Using NASA Land Information System and MODIS Datasets to Improve USBR's RiverWare Decision Support Tool

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Interim Project Meeting
Towards Verification and Validation Reporting
Updated Sept 17, 2007

Extending the societal and economic benefits of Earth science research, information, and technology **...**

1) Introduction to this NASA Water Management Applications Project

Introduction

- Accurate and timely hydrometeorological information is essential for reservoir operations and river basin management conducted at the Bureau of Reclamation (also known as Reclamation or USBR) facilities.
- Consequently, river basin managers must have timely data from remote areas that are often inaccessible in winter, and have a means of quickly analyzing the impacts of precipitation and snowmelt on streamflow for routine river system management and emergency responses to extreme events.
- Therefore, Reclamation uses a variety of hydro-meteorological observing systems that it maintains and cooperates with other agencies in collecting additional data and to use the data for their decision support tools.

2) Objectives of the Project and Relevance to NASA's Application Science Program (ASP)

Overview

Purpose of Project::

Provide spatially integrated snowpack data from NASA's Land Information System (LIS) and satellite sensors to help improve Reclamation's Yakima Office's current models and decision support systems (like RiverWare).

Goals::

- Employ LIS land surface models (LSMs) and modeling framework to simulate spatial snow conditions in the Yakima River Basin
- Incorporate NASA satellite data (i.e., MODIS) in modeling framework
- Test LIS snow fields in Reclamation's MMS and RiverWare modeling systems for the Yakima area

Main Objectives

- The main objective of this project is to test and demonstrate whether LIS modeled snow products add improvement to USBR's operational Modular Modeling System (MMS) forecasts of streamflow and storage products which are used as inputs to RiverWare.

Main Objectives (con't)

- Validate and determine which LSM in LIS may capture more realistic snowpack conditions for streamflow forecasts
- Validate and assess the applicability of MODIS Snow Cover Area (SCA) in "guiding" the LSM to further improve snowpack conditions
- Using the improved LIS modeled snowpack variables to initialize the USBR's operational modeling system and DST, like RiverWare

Contributions to the NASA ASP

- Collaboration with USBR to enable and enhance the application of NASA's Earth System science research results for use in partner's DSTs.
- **Focusing on**:
  - Estimating water storage – reservoir, snowpack, soil moisture
  - Modeling and predicting water fluxes – evapotranspiration, precipitation, river runoff.
- Identify and assess USBR water management responsibilities, plans and DSTs
- Evaluate capacity of NASA Earth system science results to support the DSTs
- **Validate and verify application of NASA Earth system science results with DSTs**
- In collaboration with USBR, document value of Earth system science results relative to its obligations and support adoption into operational use

Water Management

Science to Decision Support

Science Models

- **LSMs:** *Mosaic, Noah, VIC, Catchment, CLM2*
- **Atmospheric Models/Forecasts:** *NCEP Eta, FSL RUC, MM5, CSU RAMS, NASA GEOS (FVDAS)*
- **River Routing/Streamflow Modeling:** *MMS, CASC2D, DHVSM, TOPMODEL, Vflo™*

Data

Monitoring and Measurements

- **Snow cover and water equivalent:** *MODIS, AMSR-e, SSMI, SMMR*
- **Soil Moisture/Water Storage:** *AMSR-e, TRMM TMI, GRACE, SMOS*
- **Radiation/Energy Budget:** *GOES, MODIS, CERES, ERBE*
- **Land Use/Cover:** *MODIS, ASTER, Landsat*
- **River discharge height (large basins):** *TOPEX/POSEIDON, ERS-1 & 2, ENVISAT*
- **Land Surface/Elevation:** *SRTM*

Inputs

Information Products, Predictions, Visualizations, and Computing

- *Runoff/streamflow*
- *ET Estimates*
- *Soil Moisture*
- *Energy Fluxes*
- *Meteorological Data*
- *Assimilation Techniques for use with remote sensing data in LSMs*
- *Research and operations involve multi-spatio-temporal scales*

Outputs

AWARDS (Agricultural WAter Resources Decision Support system)

- **ET Toolbox – Estimate high resolution daily rainfall and water depletion through evapotranspiration (crop, riparian, open water)**
- **Used as input into RiverWare**

RiverWare

General river basin modeling environment for operations and planning

- **Allow users to model any river basin, manage data input and output efficiently enough for near real-time operations**
- **Integrates reservoir systems, including flood control, water supply and quality, and hydro-electric power-dam operations**

Outcomes

Value and Benefits

- Improved water supply estimates and predictions

Improve ET estimates for riparian and agricultural areas for irrigators

- Help water resource managers make more informed decisions to help meet hydrologic and ESA needs
- Use of soil moisture estimates can improve monitoring effects of drought conditions

Impacts

Evaluation Report Summary

- The Evaluation Phase was designed to evaluate applicable Reclamation DSTs and determine which NASA products show the most potential for improving DST performance and/or outcomes.
- Select NASA products were identified as having potential to be adapted as either an indirect input or customized specifically to become a direct input into the DST component, MMS, and then into RiverWare itself
- For each NASA product, it is necessary to verify that it fits with system goals, then validate that the NASA output to be in the DST is in the same format that is currently used by Reclamation water managers.

3) Description of the DST

Description of the DST

- **RiverWare and Integrated Model versions::**
  - Provides a flexible framework for developing and running site specific models that incorporate the “law of the river,” other policy constraints, and physical processes including hydrology, structural and natural operating constraints like imposed dams, etc. (http://cadswes.colorado.edu; Zagona et al., 2001).
  - Within each river system, RiverWare requires streamflow hydrograph estimates as input at many locations throughout the system.
  - Used in long-range planning and short-term operations

Description of the DST

- **RiverWare and Integrated Models**
  - As part of the overall RiverWare operational modeling system, the USGS Precipitation-Runoff Modeling System (PRMS) and the Modular Modeling System (MMS) are used to generate forecasts of streamflow and storage products.

4) Purpose and Background of Validation and Verification (V&V) Report

Goals of the V&V Report

- ***Validation and Verification*** — measure the performance characteristics of data, software tools, and/or methods to meet the requirements for a USBR's DST operations.
  - The V&V process ensures that NASA products can be added to or substituted within the DST without further DST development.
  - Interoperability -- Determining how well certain NASA satellite and modeled products fit with the USBR DST, Riverware
  - Design and Implementation – Customizing and validating relevant NASA products to be used by the DST

Relevant V&V Procedures

- Measure the performance of relevant MODIS products and LIS land surface modeling products to determine their ability to initialize streamflow forecasts made by USBR.
  - **Validation –** Evaluate and determine appropriate NASA products for use in improving streamflow forecasts and meeting the end user's needs
  - **Verification -** Evaluate how each relevant NASA product performs against independent observations and products.

5) Background and Description of NASA's Satellite and Modeled Products Used in this Project

NASA Data Products to be Tested

Potential NASA data products that could be used as inputs by RiverWare, include::

- LIS modeled output:
  - snow (liquid water equivalent),
  - evapotranspiration, and
  - soil moisture and temperature
- Primary data for evaluation include MODIS land products (land cover, snow cover, surface temperature), LIS water availability products, and AMSR-E snow water equivalent and soil moisture products.

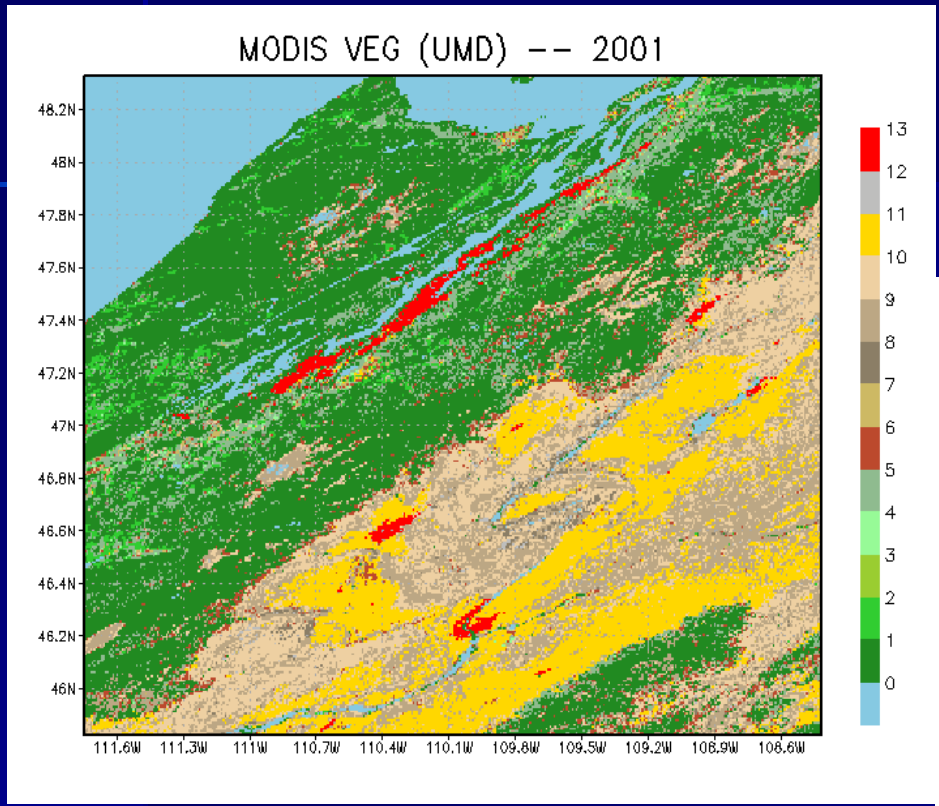
MODIS Datasets

- **Terra/Aqua Satellite's ~1 km Moderate Resolution Imaging Spectroradiometer (MODIS) products (version 4):**

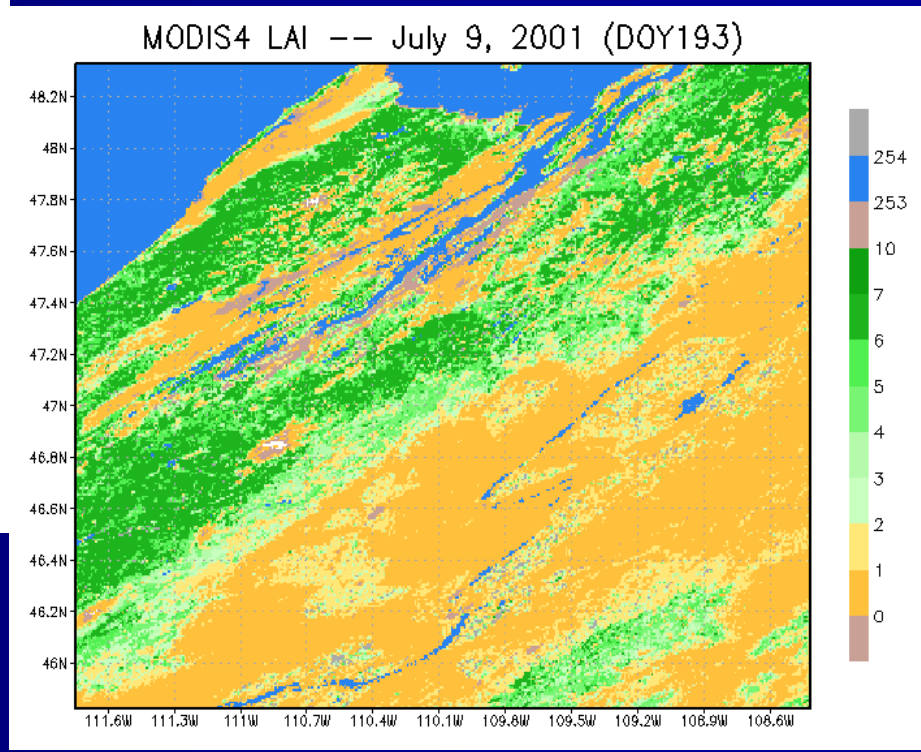
- Land Cover
- Continuous Veg. Fraction
- Snow Cover Area (SCA)
- Leaf Area Index
- Land Surface Temperature

The above products are used in the LIS model simulations, except the land surface temperature will be used in future work.

Examples of MODIS Datasets used as parameters in the LIS LSMs



MODIS v4 Land Cover Type



MODIS v4 Leaf Area Index

Land Information System (LIS)

- The LIS software is developed to parameterize, force, and constrain multiple land surface models with data from ground and space-based observing systems. It builds onto the original NASA/GSFC Land Data Assimilation System (LDAS) projects.
- **Three land surface models (LSMs) were originally evaluated for this project:**
  - Mosaic LSM – NASA GSFC
  - The Community Land Model, version 2 (CLM2)
  - NOAA's Noah Land Surface Model, version 2.7.1
- **Meteorological Forcing: NLDAS 1/8 deg Dataset**
  - NOAA's Eta Data Assimilation System data (EDAS)
  - Merged Stage II Doppler Radar and CPC Rain gage products
  - UMD (Pinker et al.) GOES Radiation Products

LIS Model Datasets used in Project and Description of Runs

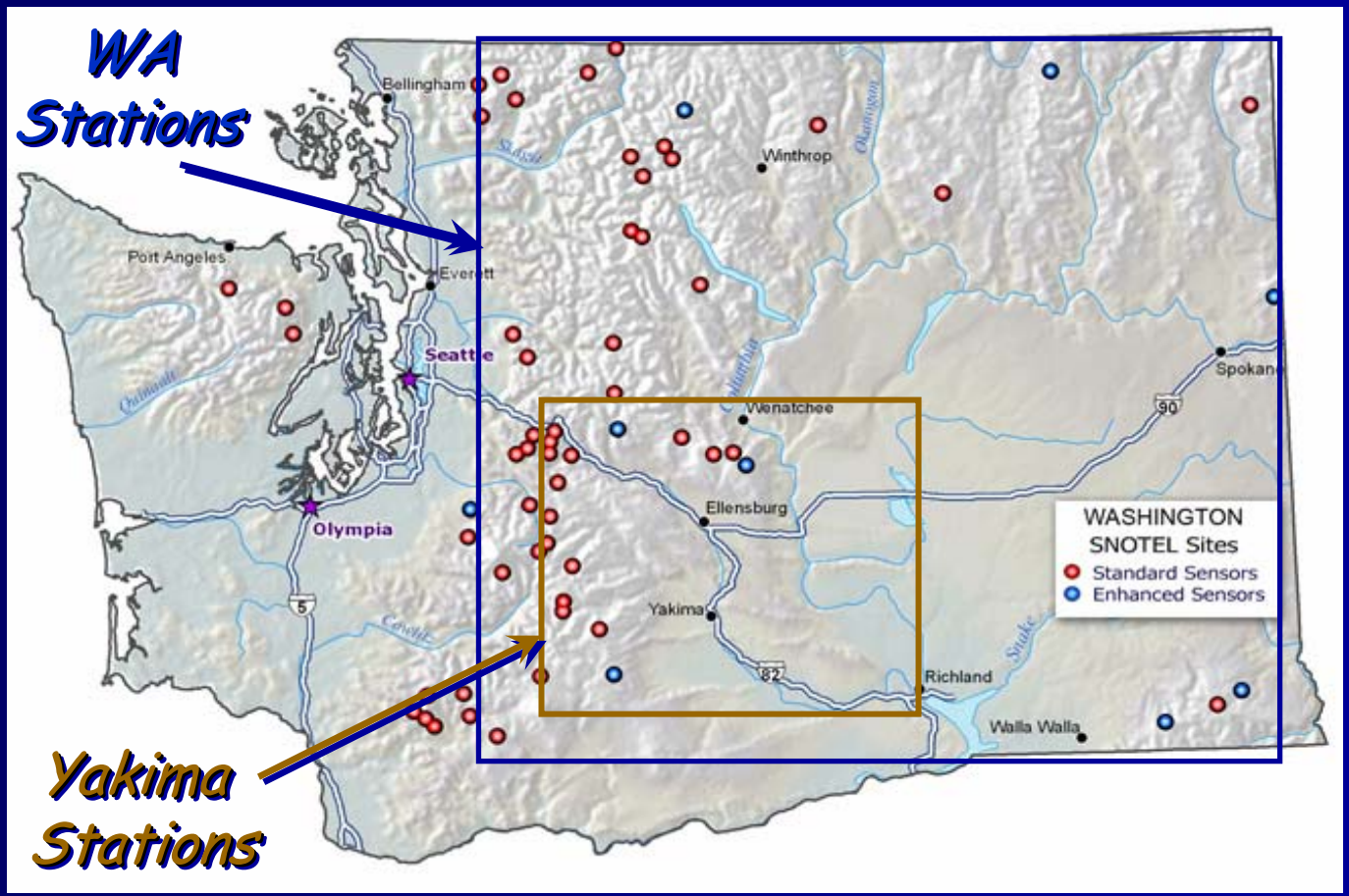
- **NLDAS 1/8 deg Forcing**
  - Downscaled to 0.01 degree resolution
  - Different temperature lapse rates were tested and used in the downscaling procedure
- **Description of Model Runs::**
  - Spinup is from Sept. 2000 to Sept. 2003; 15 minute timestep
  - Output fields are at a daily temporal resolution written at 8:00Z (reflecting local midnight, MST)
  - 3 years of LIS simulation generated for Water Years 2004-2006

Other Model Parameters

- Elevation – National Elevation Dataset
- Snotel, Agrimet, and Hydromet Datasets used to develop local temperature lapse rates
- Statsgo Soil Parameters

Washington State and Yakima River Basin Areas: Areas of Interest

USDA NRCS SNOTEL Sites for WA



6) V&V Objectives and Metrics for the Relevant NASA Products

V&V Tasks Undertaken for this Project

- Validate MODIS SCA
- Validate NLDAS Temperature and Precipitation Fields
- Validate LSM snowpack conditions (e.g., SWE)
- Prepare satellite-based model parameter and snow cover area maps to be integrated into the LSMs
- Test and validate different assimilation approaches to incorporate MODIS snow cover into the LSM(s)

Reclamation's RiverWare Metrics for the Yakima River Basin

- USBR Yakima Office's integrated, operational modeling framework with MMS will be initialized, by area, with both SWE products and compared with control MMS simulated flows (which will be the baseline run), USGS stream gage measured flows, and possibly RFC flow values
- Comparisons of daily and monthly sub-basin volumes of total snowmelt and runoff from both products (though for SNODAS, only snowmelt volumes will be looked at)

7) V&V of the MODIS Products:

a) MODIS Land Cover

b) MODIS Leaf Area Index

c) MODIS Snow Cover Area

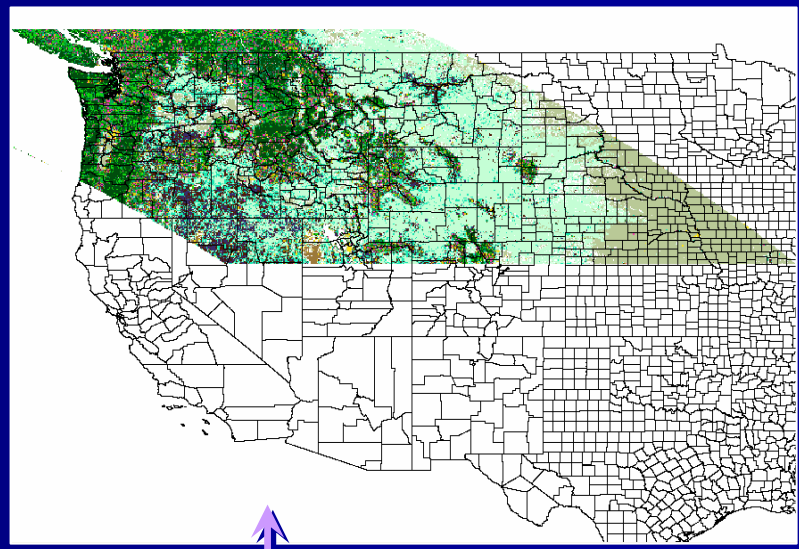
a) Validating the MODIS Land Cover Product

MODIS Land Cover Product Validation

MODIS Land Cover Type Yearly L3 Global 1km SIN Grid V004 (MOD12Q1) images from:

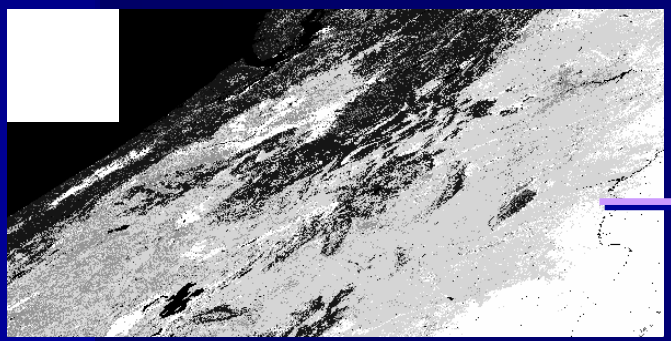
http://edcdaac.usgs.gov/

(for 2001)



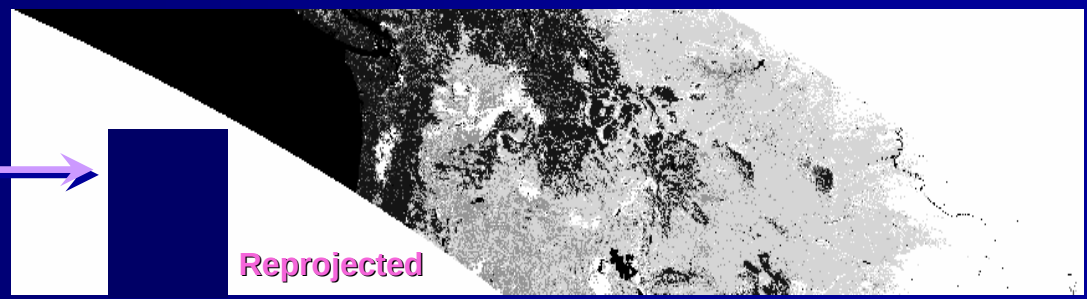
Opened in ArcGIS

Mosaicked Tiles



Land Cover Type 2 –UMD (Sinusoidal)

Reprojected

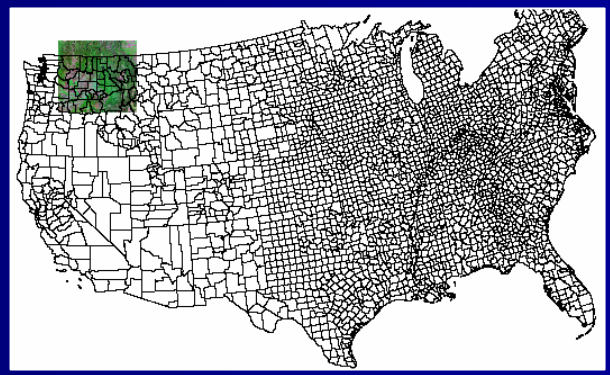


Land Cover Type 2 –UMD (Geographic)

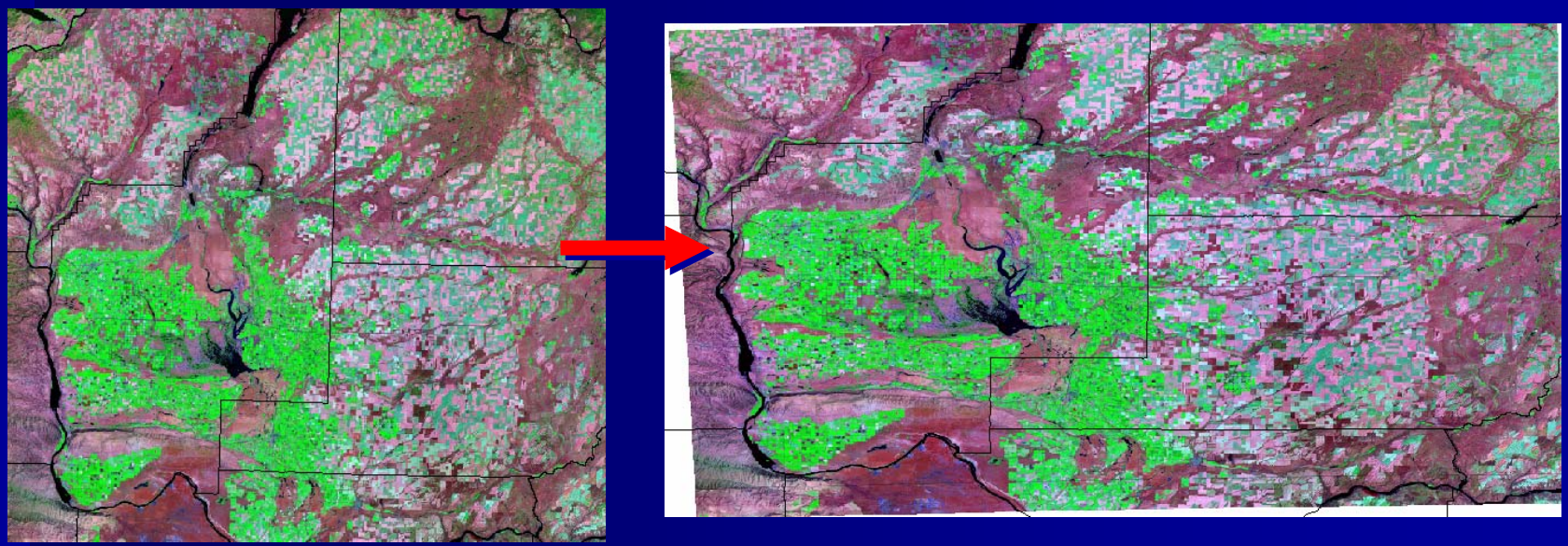
Used pan-sharpened Landsat 7 Image for 2000 for MODIS Land Cover Registration and Validation

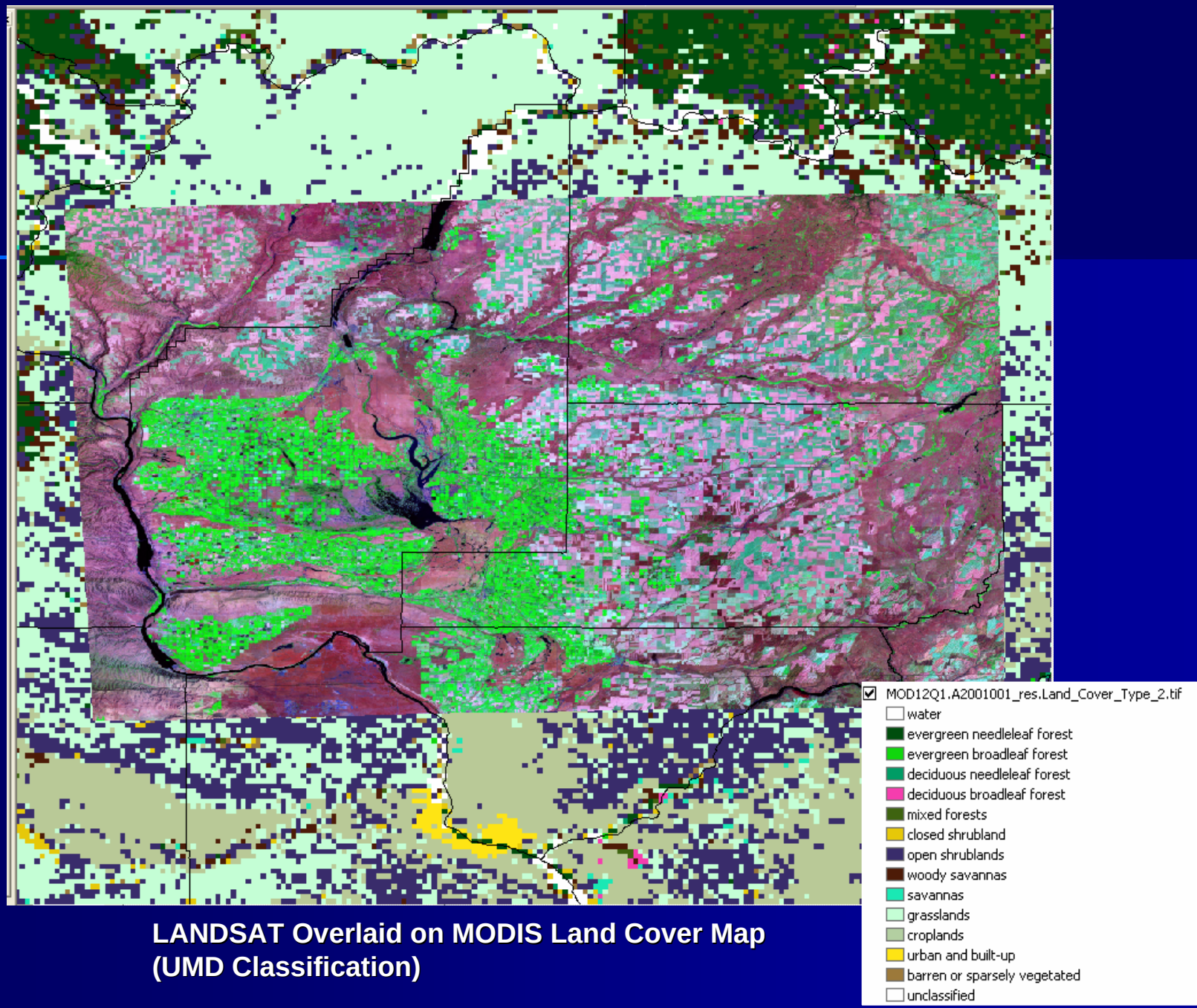
(bands 7,4,2; 14.25 m res.; from https://zulu.ssc.nasa.gov/mrsid/mrsid.pl)

Landsat 7 UTM 11N and county boundaries (ESRI)



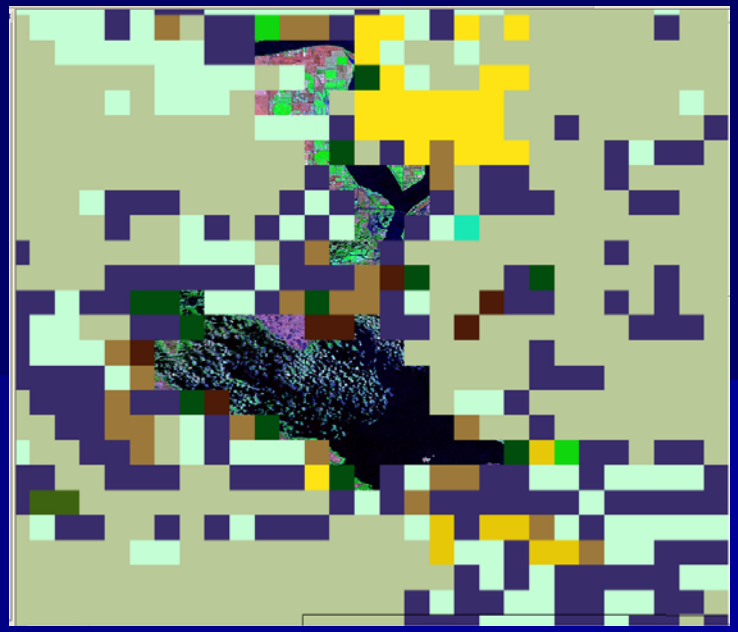
Landsat 7 Reprojection from UTM 11N to Geographic



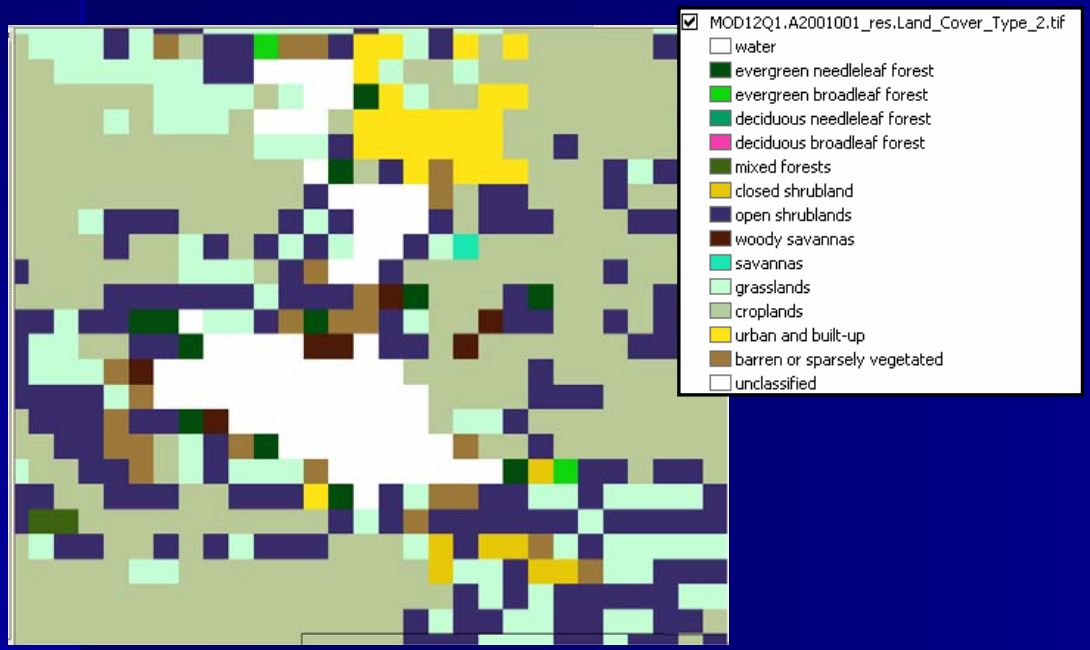


LANDSAT Overlaid on MODIS Land Cover Map (UMD Classification)

Subset of Landsat in Geographic (black = water)

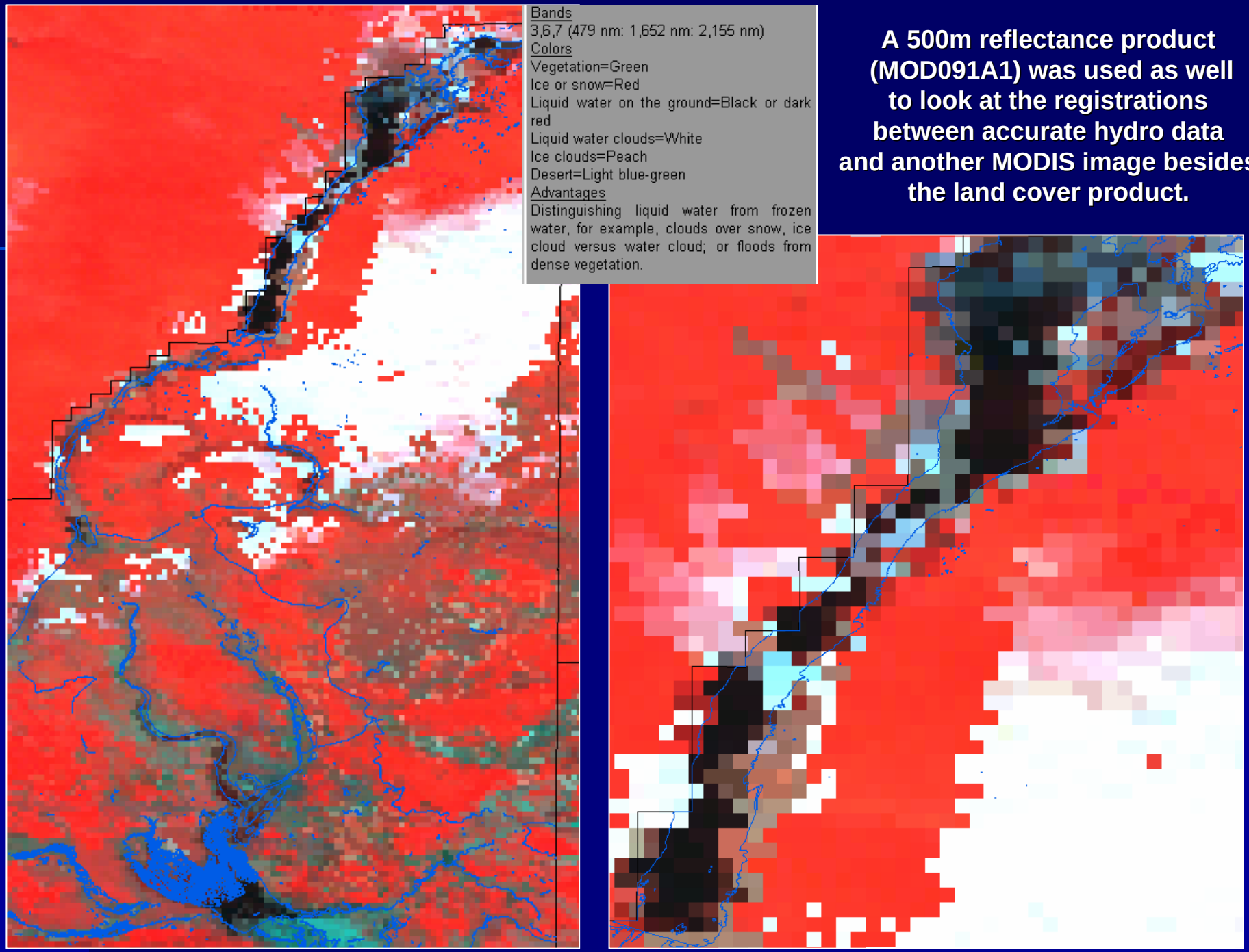


MODIS overlaid on Landsat – the water areas match up pretty well



Subset of MODIS in Geographic (white = water)

Due to the differences in dataset resolutions, it can be difficult to compare landcover areas. However, a study can be performed to compare the Landsat landcover classes that fall within a MODIS pixel, though georegistration is not doable at this time.



A 500m reflectance product (MOD091A1) was used as well to look at the registrations between accurate hydro data and another MODIS image besides the land cover product.

b) Validating the MODIS Leaf Area Index Product

Validating the MODIS Leaf Area Index Product

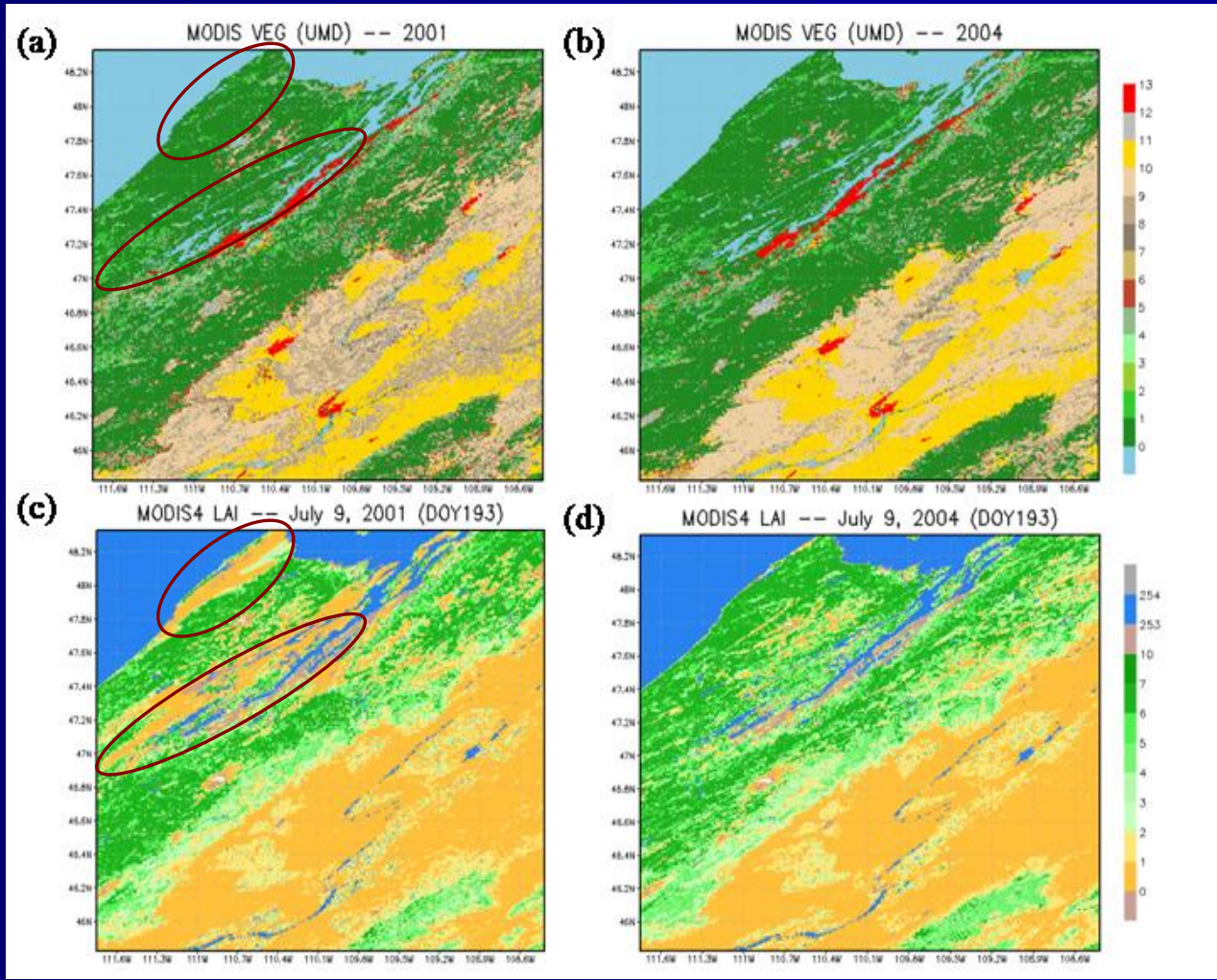
- The Terra MODIS, version 4, Leaf Area Index (LAI) product is developed at Boston University** and is further processed to be used as a spatial, varying parameter in some of the LIS LSMs.
- The product is evaluated against MODIS land cover maps (UMD classification), in-situ observations and literature-based references.
- 6-year monthly climatologies are calculated for each pixel and modifications are made based on MODIS land cover type (e.g., evergreen needleleaf).

** http://cybele.bu.edu/download/manuscripts/ywze02.pdf

Yang et al., 2006: MODIS Lear Area Index Products: From Validation to Algorithm Improvement. IEEE Trans. On Geosc. And Rem. Sens., 44. (7), pps. 1885-1899.

Figures 1a and 1b are MODIS v4 land cover classification maps (UMD classification) for years 2001 and 2004 (respectively), and Figures 1c and 1d are two sample MODIS LAI files for a mid-summer month, corresponding to the years of the land cover maps.

For 2001, two dark red ellipses are drawn in Figures 1a and 1c, highlighting two regions where the summertime LAI has dropped to values near 1, which is considered to be very low for summertime LAI conditions for evergreen needleleaf forest areas, as indicated in the land cover map plots (i.e., Figure 1a).



Correcting LAI Values Associated with Evergreen Needleleaf Forest Pixels

- Corrections are needed for this MODIS LAI product, since pixels identified as evergreen needleleaf forest pixels tend to underestimate LAI values.
- Some field studies show LAI measurements in the Pacific Northwest region ranging widely from 0.5 to 12 for evergreen needleleaf pixels, depending on the age of a particular forest stand and the density of the tree area *(Waring and Franklin, 1979; Scurlock et al., 2001).*
- Typically, evergreen needleleaf trees in this area may have LAI values around 6.0, which are much higher than found currently in the MODIS LAI dataset for this region.

To increase wintertime LAI values for evergreen needleleaf pixels, limits are set to adjust the LAI values, and the MODIS (MOD44b) product (v4), vegetation continuous fraction ("VCF") is used for additional modification.

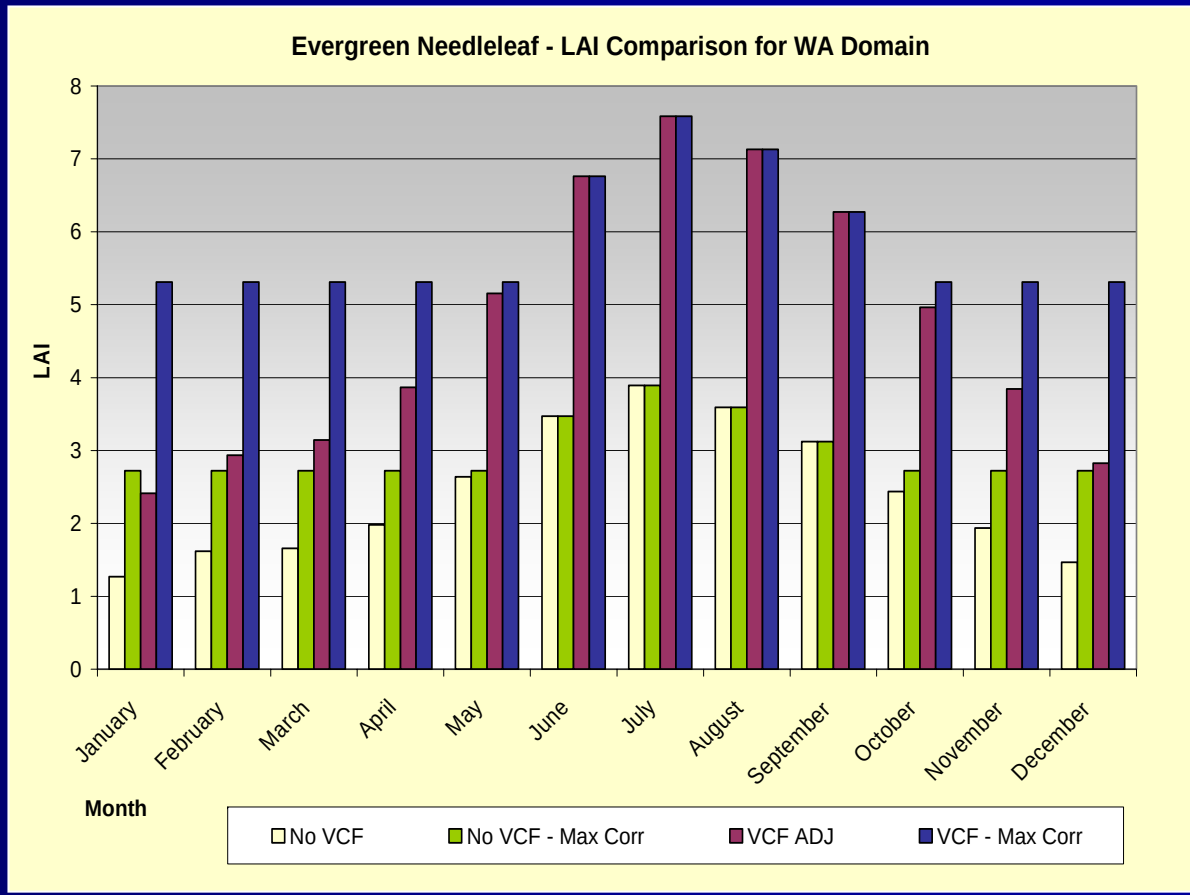
1) "No VCF":: Original LAI Values

2) "No VCF – Max Corr":: Correction using 70% of the maximum LAI of the twelve monthly climatological values**

3) "VCF ADJ":: LAI values adjusted using the VCF "tree-only" product

4) "VCF – Max Corr":: 2) and 3) combined

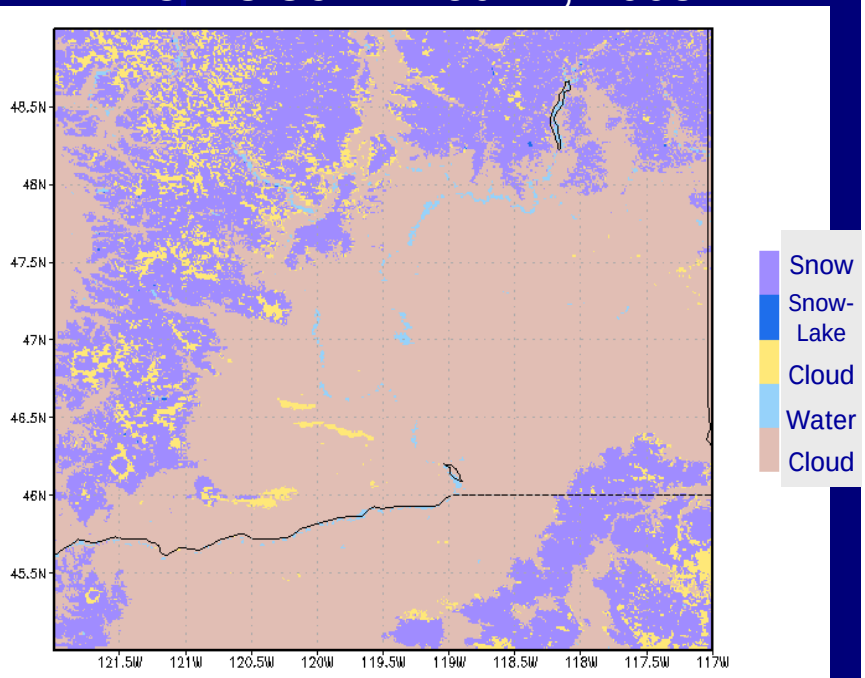
** The empirical constant of 0.70 is the suggested value for evergreen needleleaf forest in some studies, like in Tian *et al.* (2004).

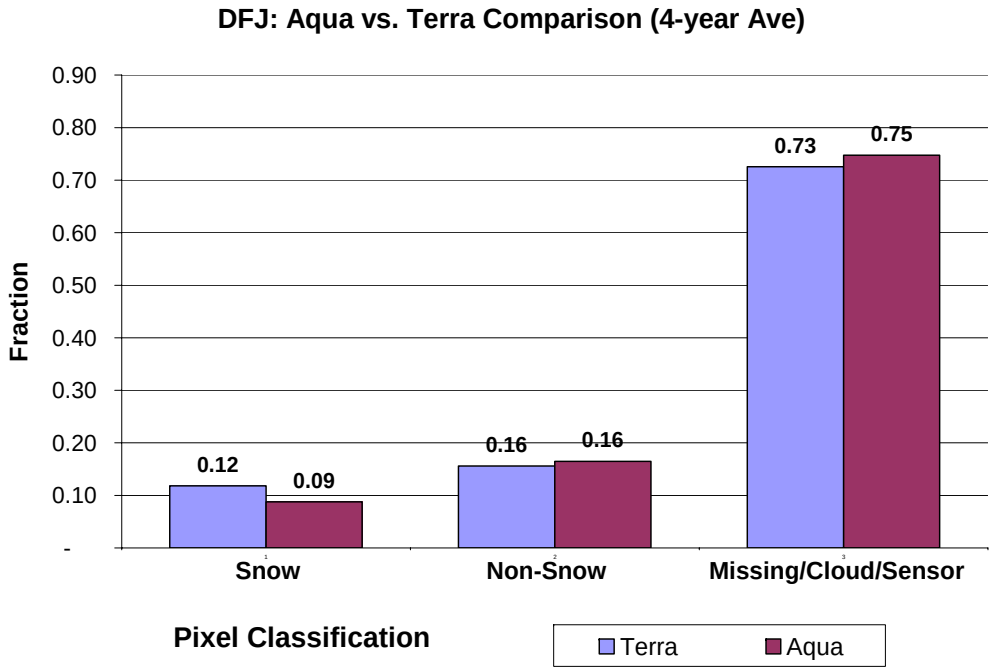


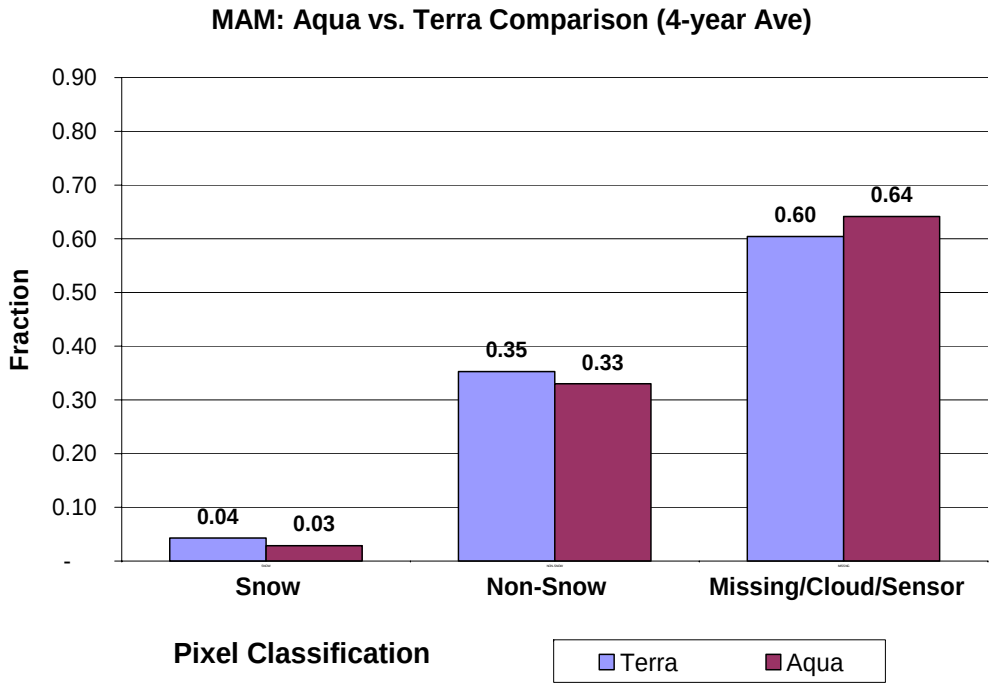
c) Validating the MODIS Snow Cover Area Product

Frequency of MODIS Snow Cover Identifed Pixels (2002-2006)

MODIS SCA – Feb.24, 2003







Validation of MODIS SCA::
Probability of Detection Analysis

MODIS Snow Cover vs. Snotel Snow Cover

POD: Probability of Snow Detection **

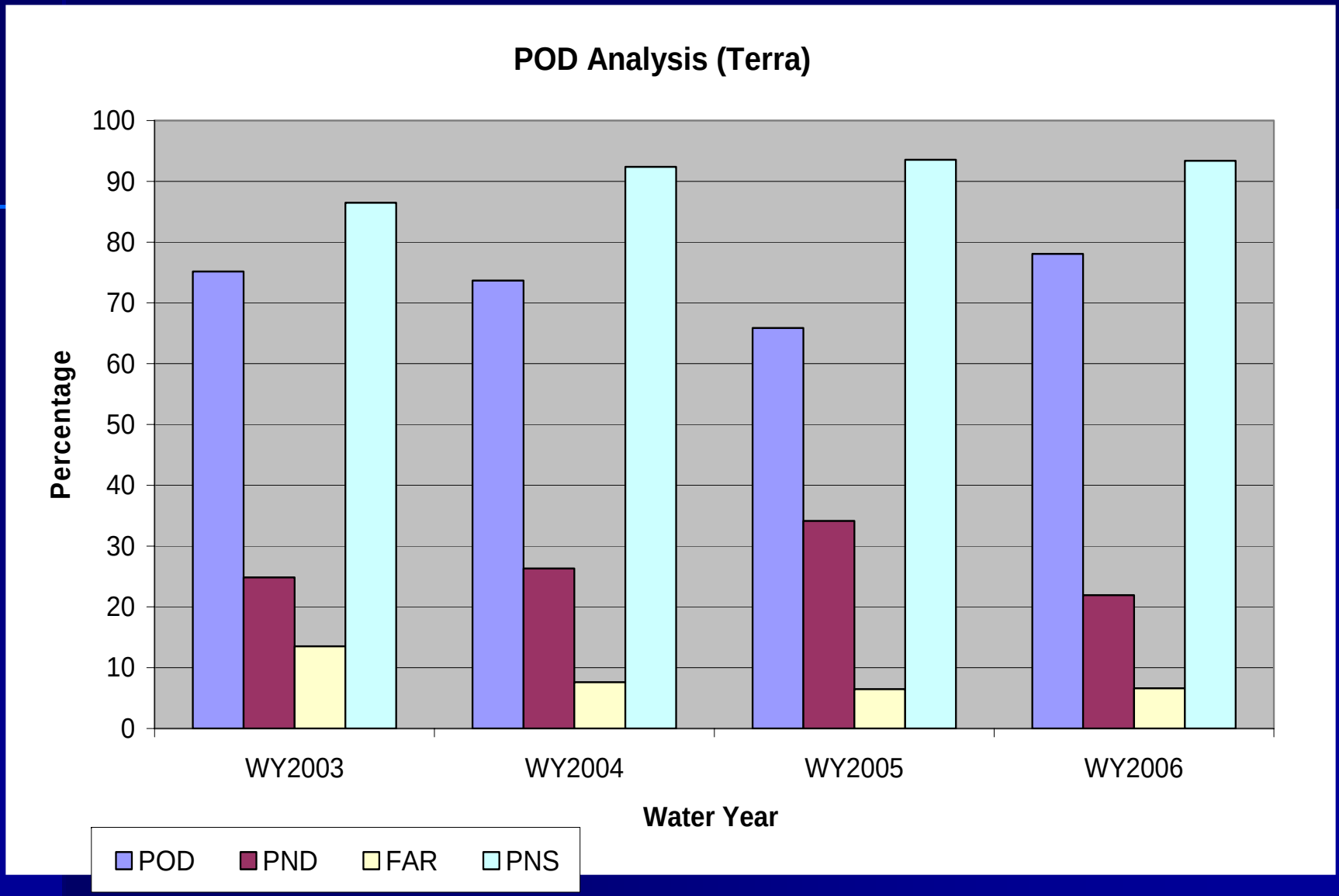
FAR: False Alarm Rate

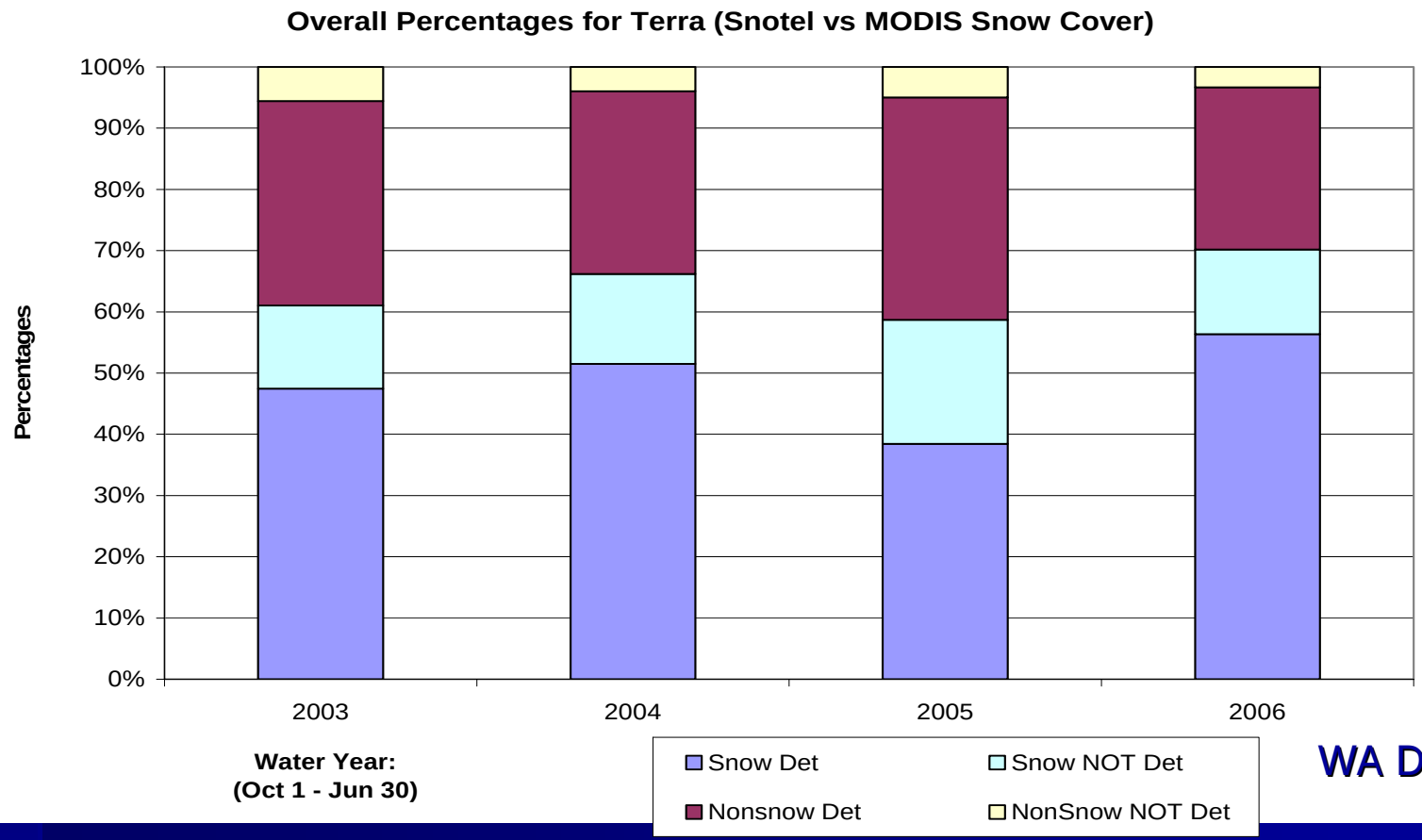
PND: Probability of NO Detection

PNS: Probability of No Snow Detection **

*** High values for these two categories indicate high accuracy of detection*

Snotel Snow Cover \ MODIS Snow Cover	Snow	No Snow
Snow	**POD****	**PND**
No Snow	**FAR**	**PNS****

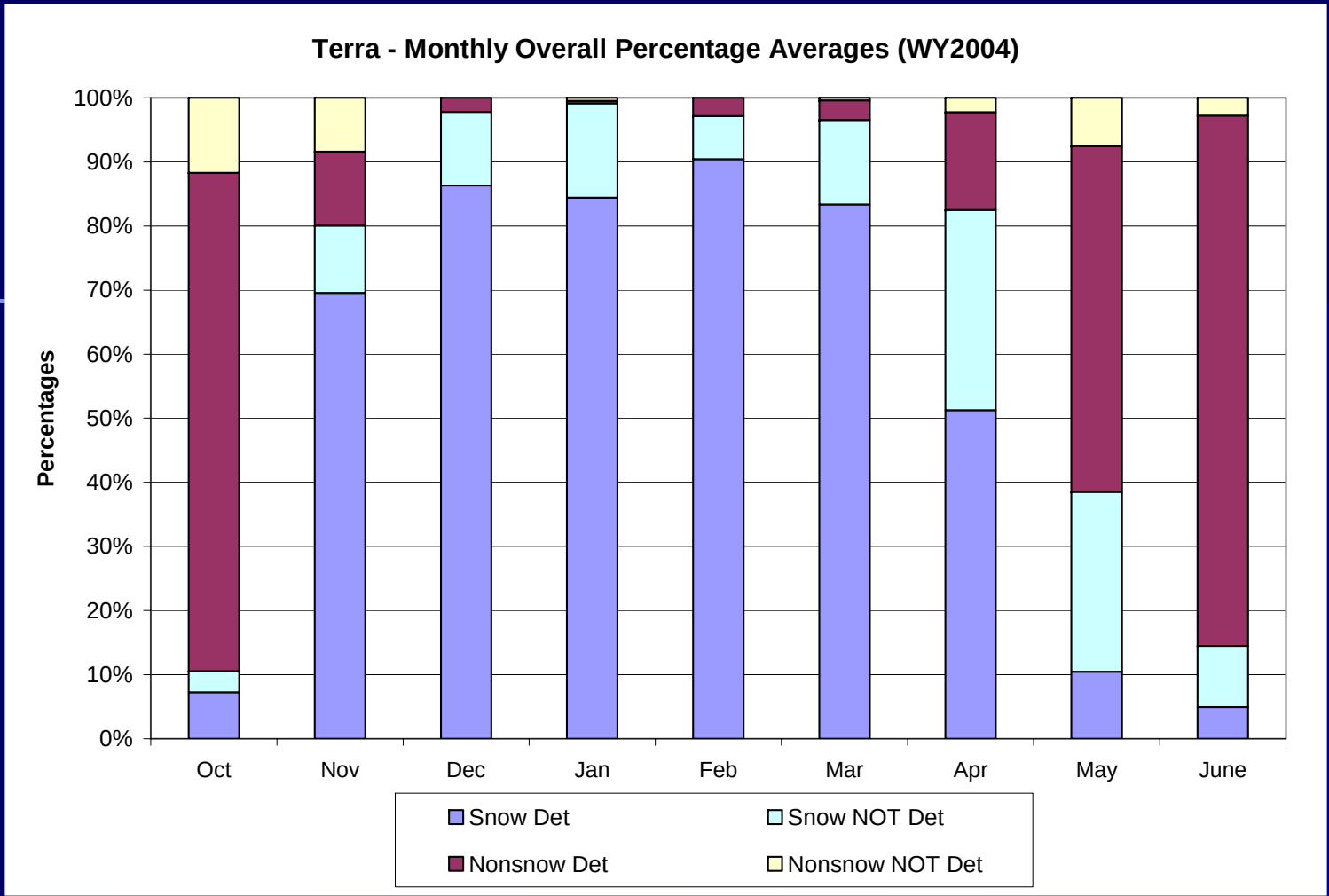

POD Analysis (Terra)
100
90
80
70
60
50
40
30
20
10
0
Percentage
WY2003
WY2004
WY2005
WY2006
Water Year
POD
PND
FAR
PNS



WA Domain

The percentages of "Snow Det" (POD; purple) and "Nonsnow Det" (PNS; dark red) indicate a level of accuracy (per year) that MODIS is able to detect the presence of snow in the WA domain.

WY	DETECTED TOTAL	NOT DETECTED TOTAL
2003	80.84%	19.16%
2004	81.35%	18.65%
2005	74.76%	25.24%
2006	82.85%	17.15%



The percentages of “Snow Det” (POD; purple) and “Nonsnow Det” (PNS; dark red) indicate a level of accuracy (per year) that MODIS is able to detect the presence of snow in the WA domain.

NOTE:: MODIS is unable to detect snow as well in April and May.

Important Questions to Address::

- How does this underestimation of MODIS SCA detection affect our ability to assimilate MODIS SCA into a LIS LSM?
- How do we best use such a binary snow cover product to help guide an LSM?

8) V&V of LIS Input and Output Variables:

a) NLDAS Forcing Fields

i. Air temperature

ii. Total Precipitation

iii. Snowfall Summaries

a) LIS LSM Output

i. Snow water equivalent (SWE)

ii. Monthly Volumetric Snowmelt and Runoff

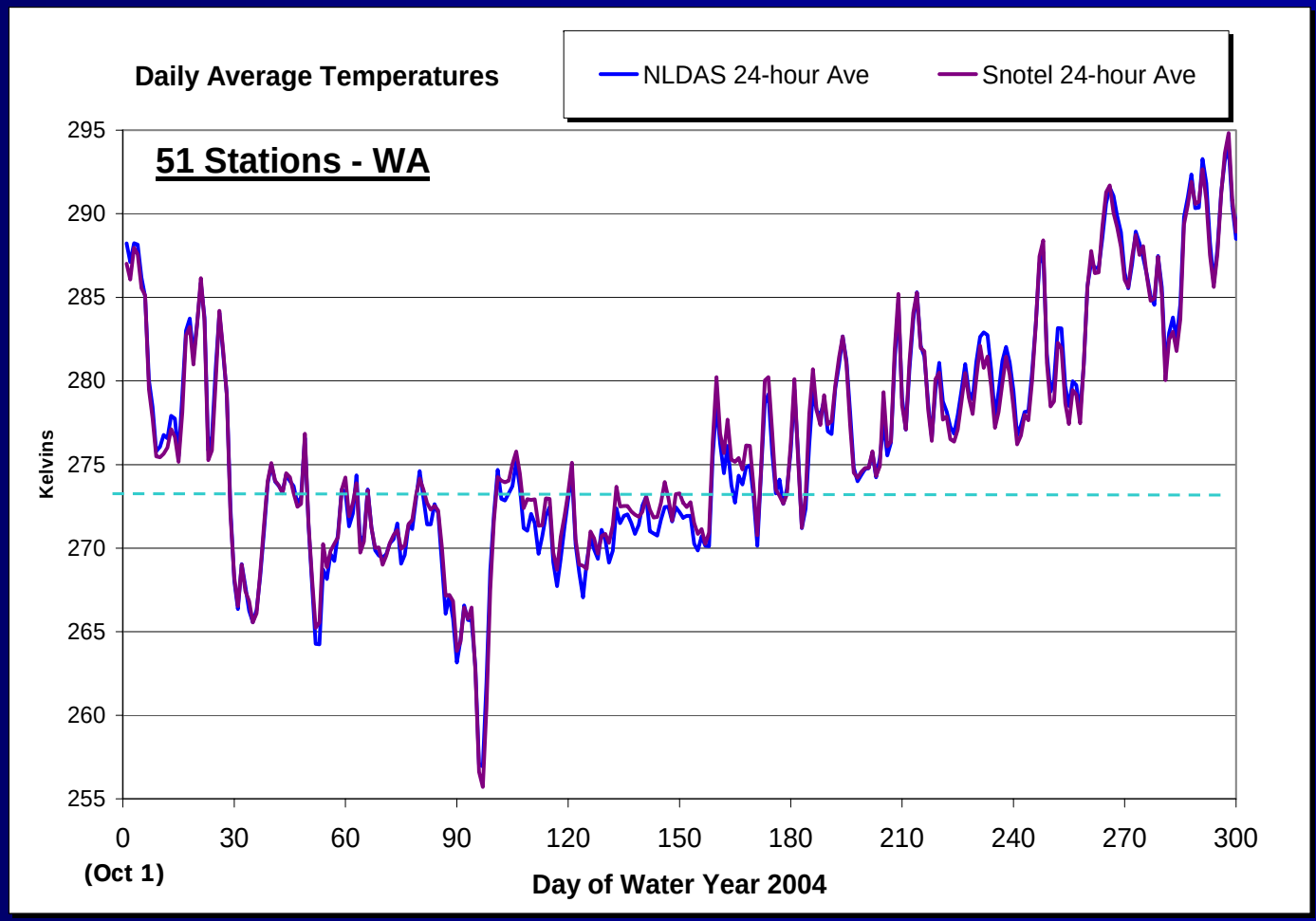
a) Validating NLDAS Forcing Variables:

Temperature and Precipitation

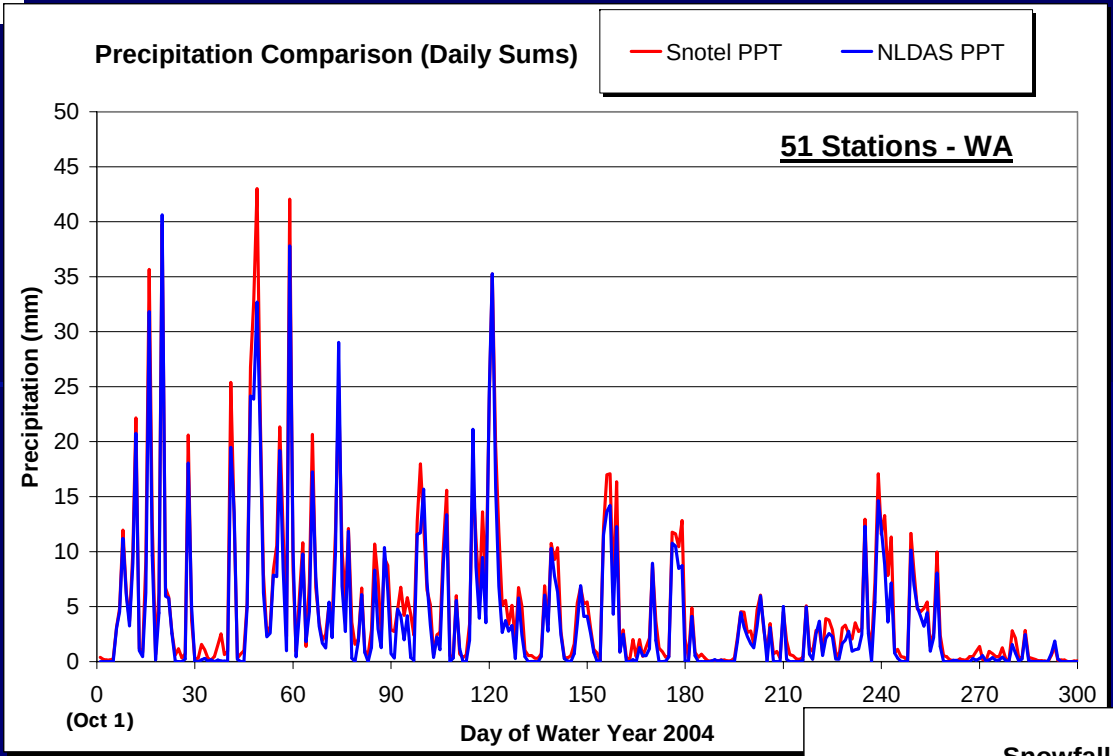
Temperature Comparison

Averaged Temperature over 51 SNOTEL stations ➔

*** For WY 2004**



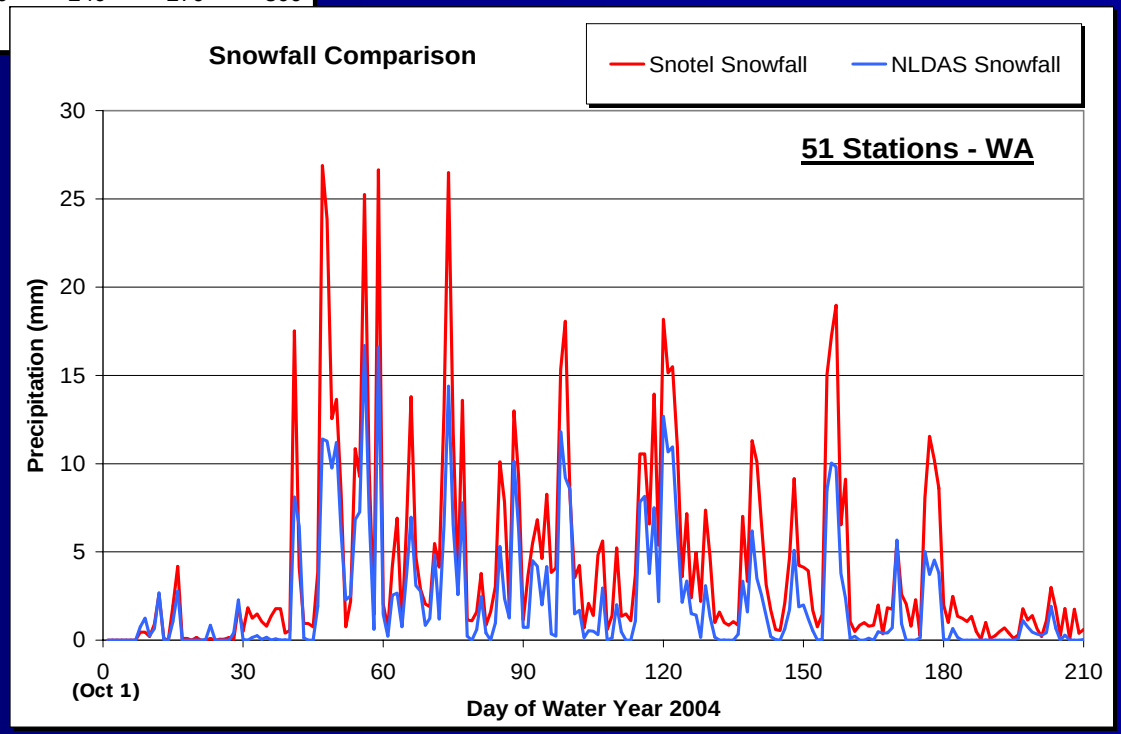
Precipitation Comparison



← Total Precip

Snowfall →

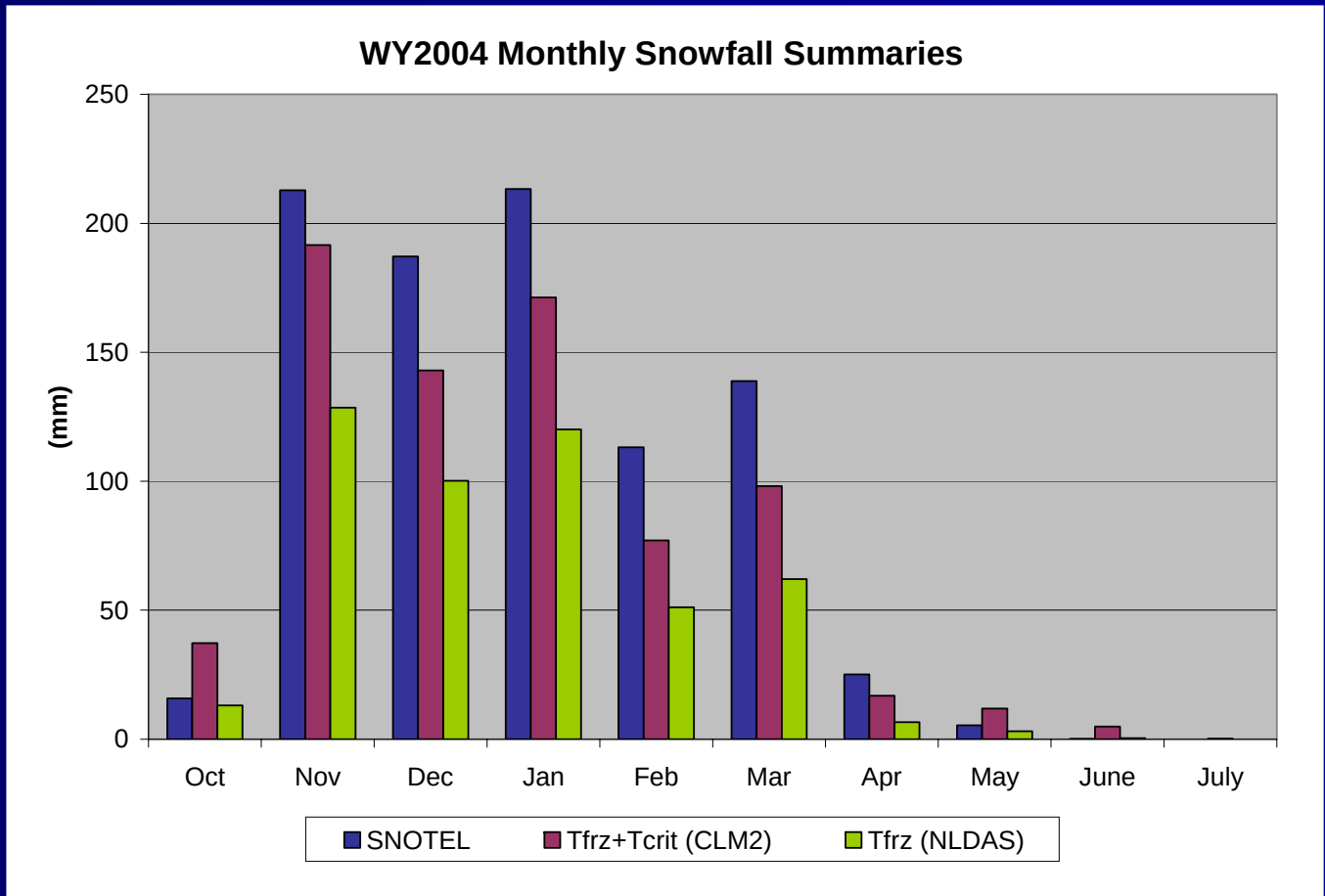
* For WY 2004



Snowfall Determination Comparison

CLM2 uses a different threshold to discriminate between snowfall and rainfall by using a "critical" temp. value (Tcrit) of 2.5°C#. Noah and other LSMs use only freezing temp. (Tfrz) of 0 °C.

Monthly total snowfall amounts (mm) compared for the Water Year 2004.

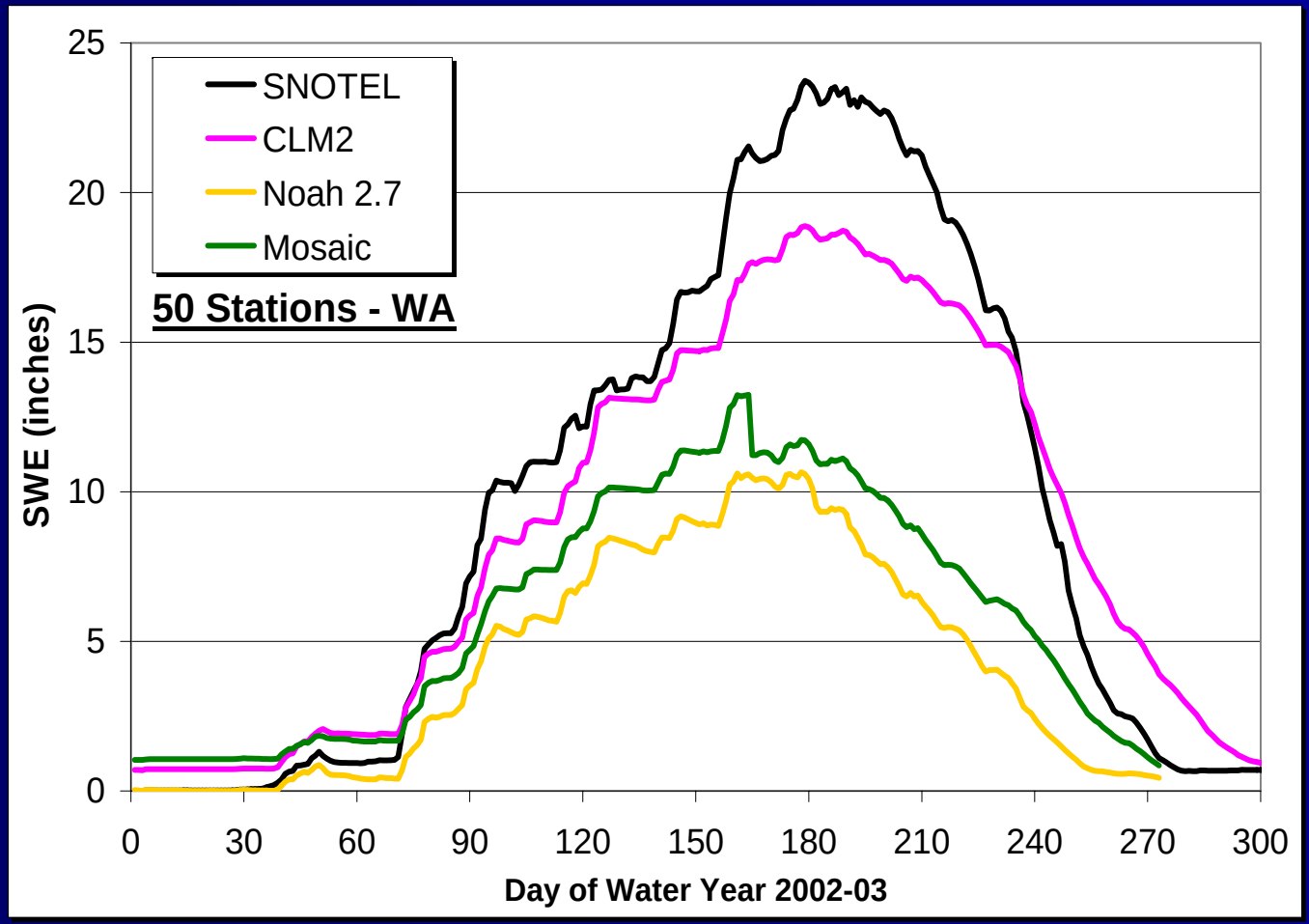


North Pacific Div., US Army Corps of Engineers (1956), Snow Hydrology, Summary Report of the Snow Investigations [taken from SNTHERM model (Jordan, 1991)]

b) Validating the LIS LSMs

LIS LSM Comparison for the WA State Domain

The CLM2, Noah 2.7.1, and Mosaic LSMs in LIS were originally evaluated for the Washington state region ("WA Domain") for Water Year 2003.



Selecting CLM2::
The "Good" and the "Bad"

- The "**Good**":: CLM2 captures the snow accumulation period (Fall months) the best over the other two validated LSMs
- The "**Bad**":: CLM2 tends to retain snowpack conditions far too long into the spring months, NOT capturing very realistic snowmelt timing

9) Calibration of CLM2 and Assimilation of MODIS SCA

Elevation Correction Experiments

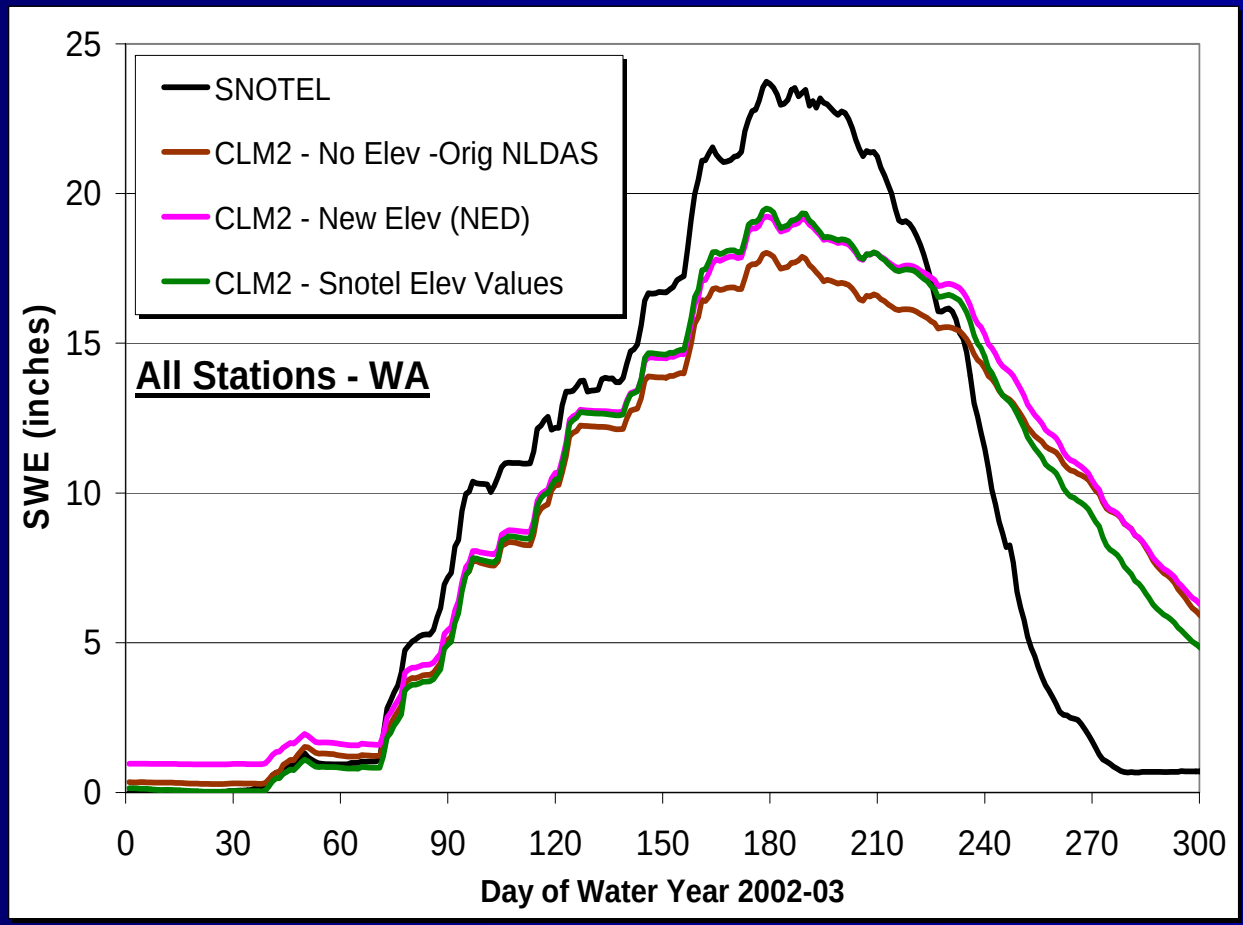
The higher resolution (~1km) NED elevation parameter is used to downscale the 1/8th degree NLDAS forcing fields to better account for topographic influence on air temperatures and snowfall determination.

"No Elev-Orig NLDAS":: Original 1/8 deg. NLDAS temperature

"New Elev (NED)":: NLDAS Temp. adjusted with ~1km NED elev field

"Snotel Elev Values":: Using local Snotel elev. values

The results showed slight improvement for the CLM2 LSM during the accumulation phase and earlier melt in late spring months. (averaged over 50 stations).

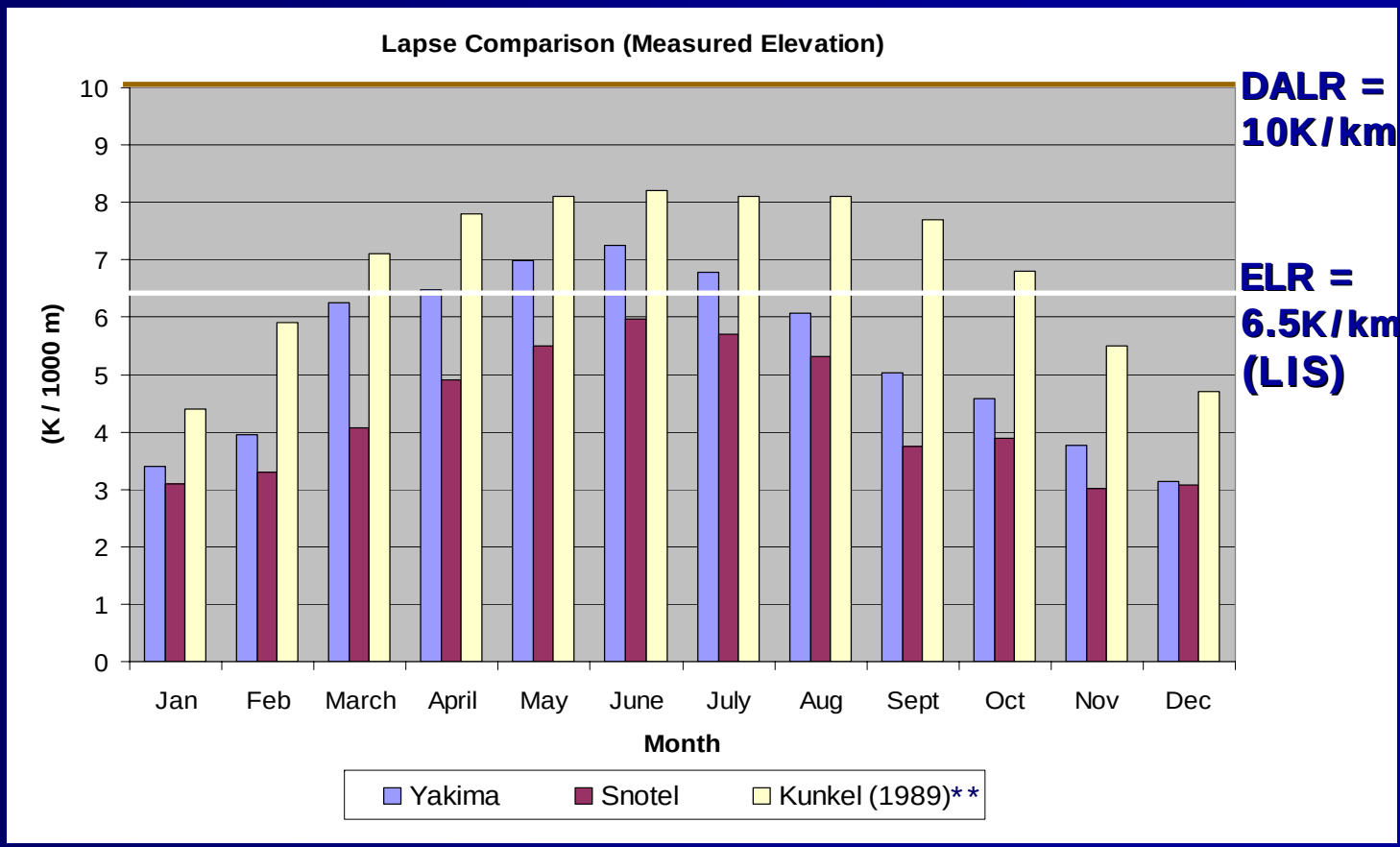


Monthly Averaged Temperature Lapse Rate Comparison

Daily Average Temperatures at Snotel, Agrimet, and Hydromet stations were used to calculate "local" monthly lapse rates for:

The state of Washington ➔ "Snotel"
The Yakima River Basin ➔ "Yakima"

Originally in the NLDAS forcing fields, the assumed environmental lapse rate of ELR=6.5 K/km is used.



***Kunkel (1989) is used in MicroMet (Liston and Elder, 2006)*

Monthly Averaged Temperature Lapse Rate Comparison

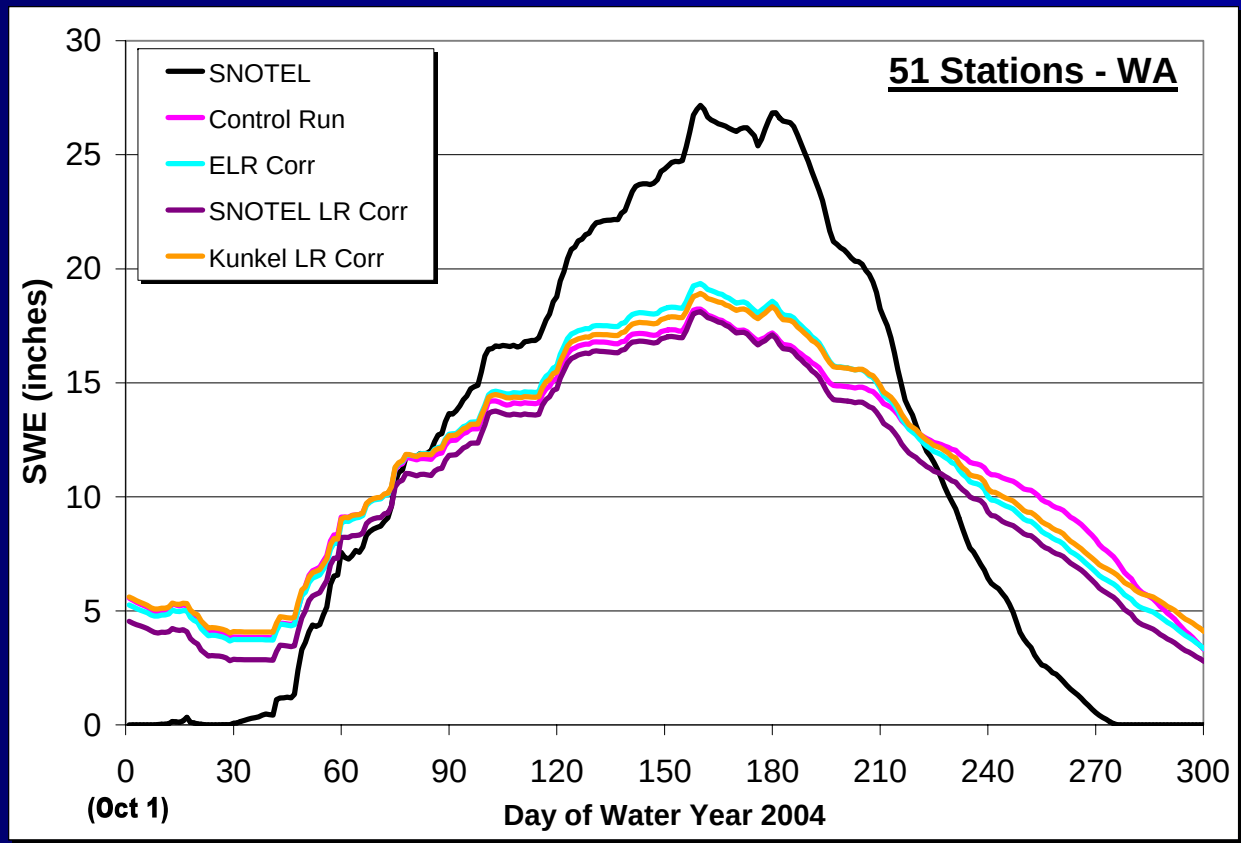
The original NLDAS forcing uses a standard environmental lapse rate (ELR) of 6.5 K/km, but it is downscaled for the ~1km LIS runs.

Daily Ave. Temperatures at Snotel, Agrimet, and Hydromet stations were used to calculate "local" monthly lapse rates (LR) for:

- The WA Domain ➔ "Snotel"
- The Yakima Basin ➔ "Yakima"

The higher resolution (~1km) NED elevation parameter is used to downscale the 1/8th degree NLDAS forcing fields, but for three lapse rates cases:

1) 1km LIS - ELR (static)
2) SNOTEL Monthly LR
3) Kunkel** Monthly LR



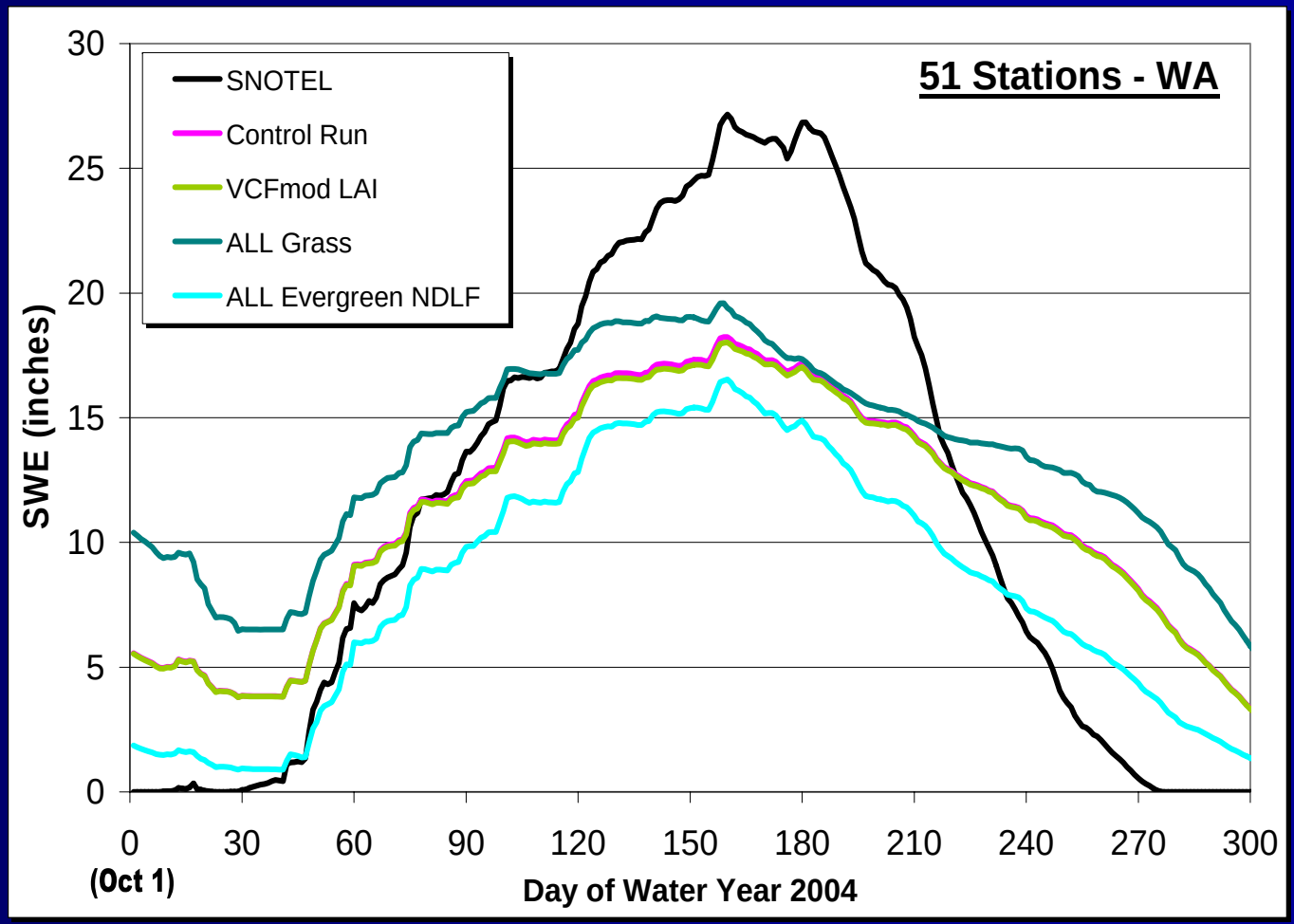
***Kunkel (1989) is used in MicroMet (Liston and Elder, 2006)*

Land Cover and Vegetation Parameter Experiments

Additional experiments were conducted to evaluate the sensitivity of CLM2 to enhanced MODIS LAI fields and land cover changes.

CLM2 uses LAI as a major vegetation parameter, but enhancing the MODIS LAI product had no or little impact on SWE.

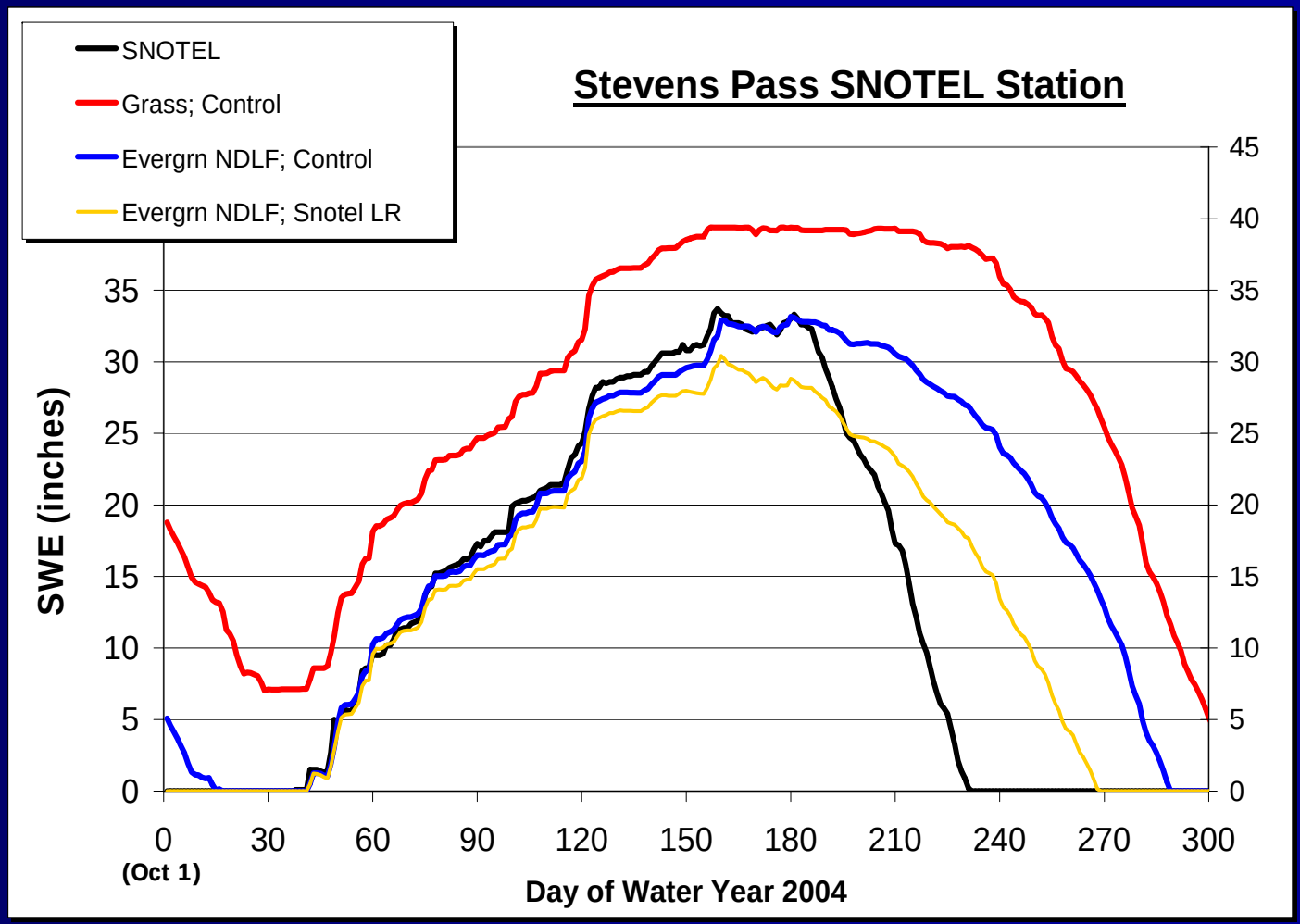
Different snow physics are called in CLM2 depending on the vegetation type. An "ALL Grass" and an "ALL Evergreen Needleleaf" case were generated and shown here.



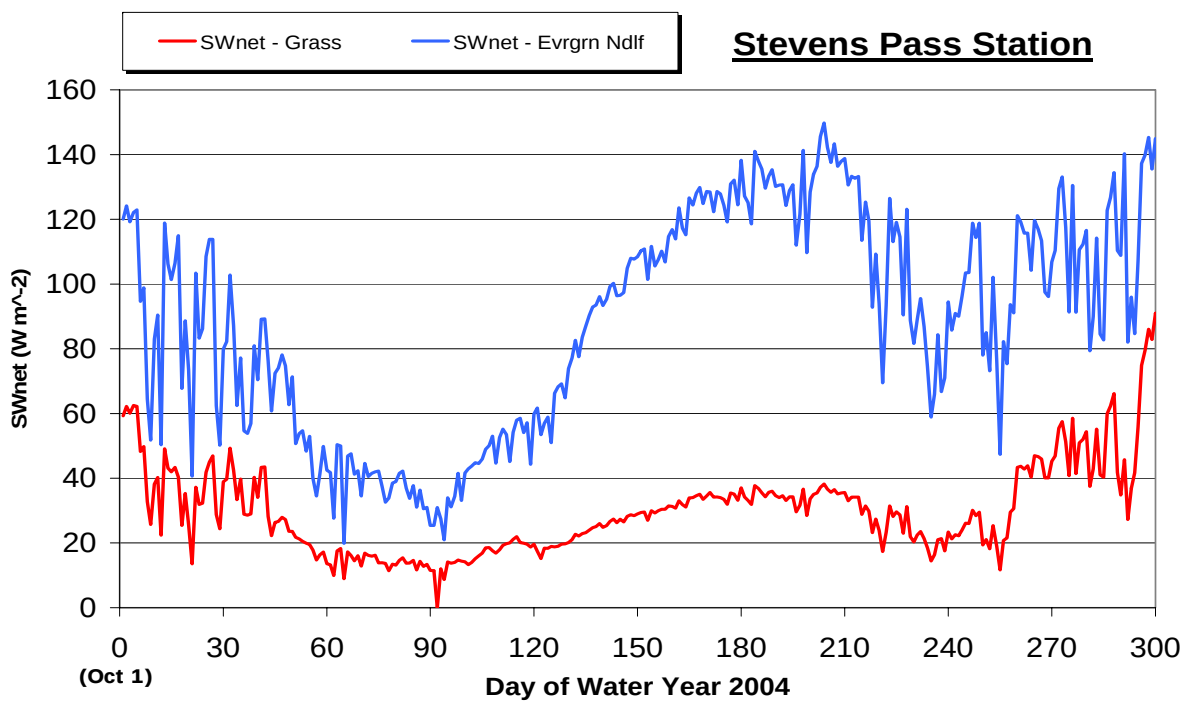
Impacts of CLM2 Snow Physics Biases (Example)

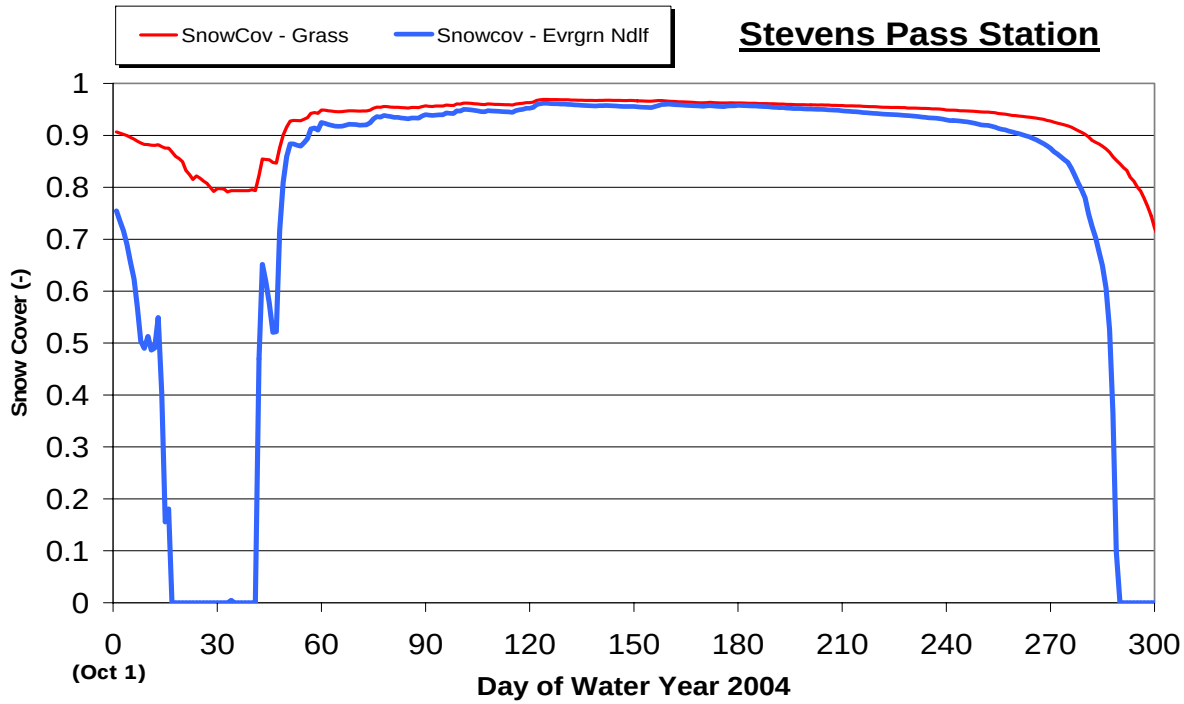
Stevens Pass SNOTEL site in WA is identified as a “grass” land cover type in the MODIS land cover map used in the CLM2 runs.

Using the SNOTEL LR results in an earlier onset of the springtime snowmelt timing.



Related Probems Affecting CLM2 Surface Temperature





Assimilating MODIS SCA into LIS CLM2:

Direct Insertion Approach

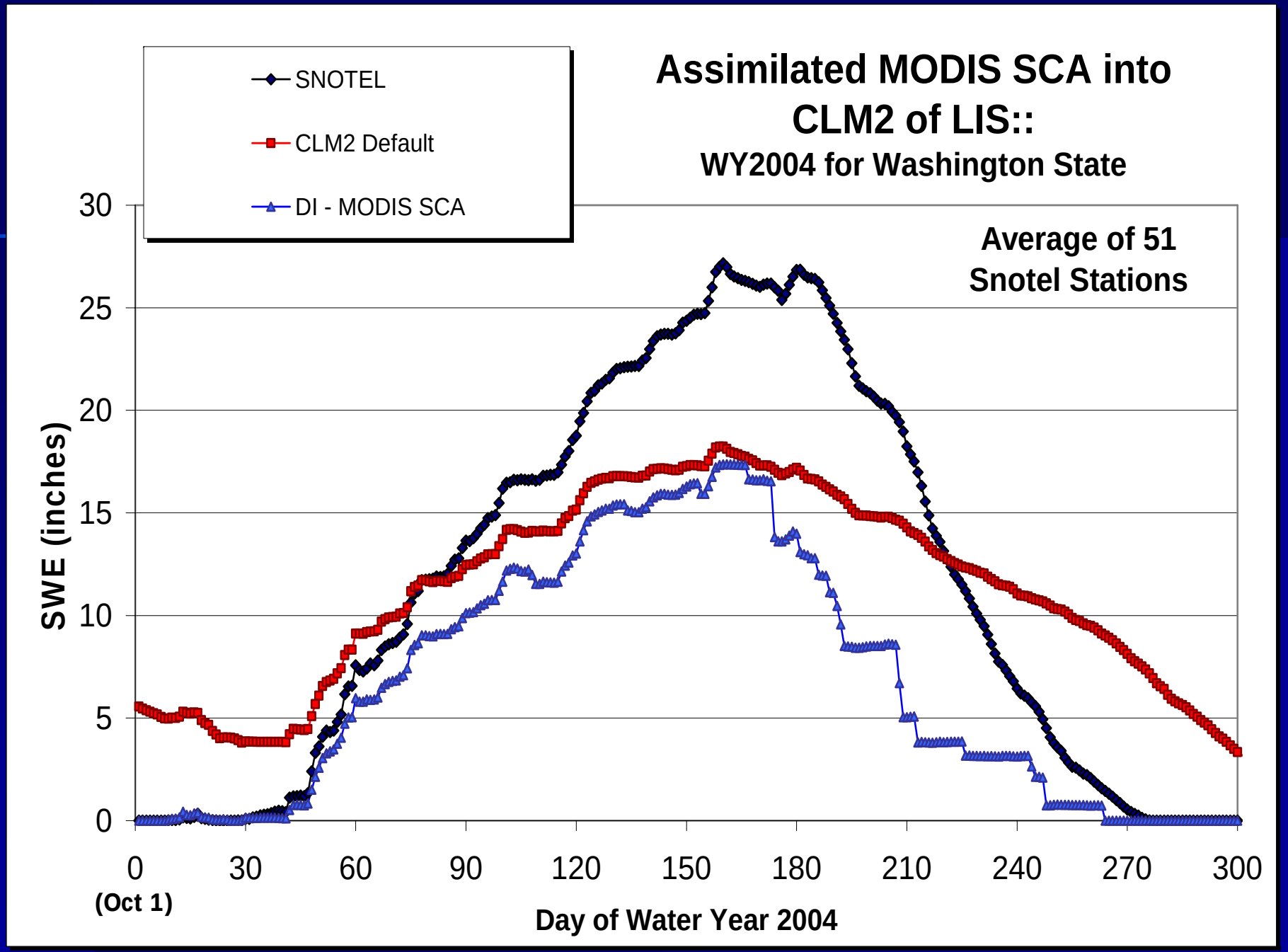
Assimilation of MODIS SCA into the CLM2 Land Surface Model

1) Terra MODIS Snow Cover Area (SCA) Dataset Preparation::

- MODIS SCA data were processed and subsetted for the WA and Yakima River Basin domains.
- The MODIS SCA data are read into the LIS v5.0 modeling environment and "directly inserted" into the CLM2 model per day

2) The Direct Insertion Assimilation Approach::

- At the time of Terra's pass overhead (~10:00 am local time), the SCA index dataset is used to determine if snow is "detected" and then compared against whether CLM2 predicted snowpack conditions for that same pixel.
  - If MODIS indicates "snow" but CLM2 does not, a nominal layer of 5 mm is added to CLM2 (based on Rodell and Houser, 2004).
  - If MODIS indicates "no snow" but CLM2 does, then an adjustment to the CLM2 snowpack (5-layer snowpack model) is made.

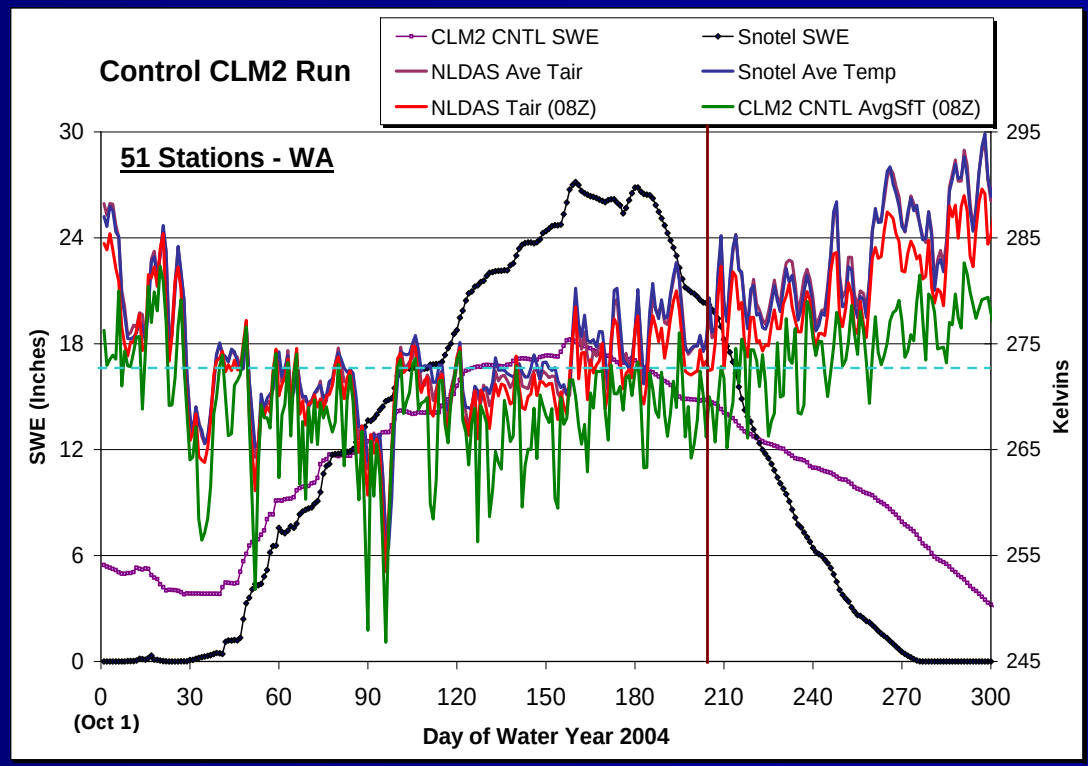

Assimilated MODIS SCA into CLM2 of LIS::
WY2004 for Washington State
SNOTEL
CLM2 Default
DI - MODIS SCA
Average of 51 Snotel Stations
SWE (inches)
0
5
10
15
20
25
30
0
(Oct 1)
30
60
90
120
150
180
210
240
270
300
Day of Water Year 2004

Assimilation of MODIS SCA into the CLM2 Land Surface Model (con't.)

3) "Temperature Correction" Approach to Modifying CLM2 SWE::

- Once the daily MODIS SCA field is compared with the CLM2 snowpack conditions, the snowpack layer temperatures are adjusted to the downscaled NLDAS air temperature field.
- This is seen as a type of "correction" to the LSM, since CLM2 has a surface cold bias in the model, causing the snowpack to remain longer than encountered in the real world.

The correction is based on how well the downscaled average air temperature field compares with the average air temperature measured at the Snotel stations.



Direct Insertion -- SCA Assimilation Process

Forcing Update (using NLDAS data):: Precip, Temp, etc.

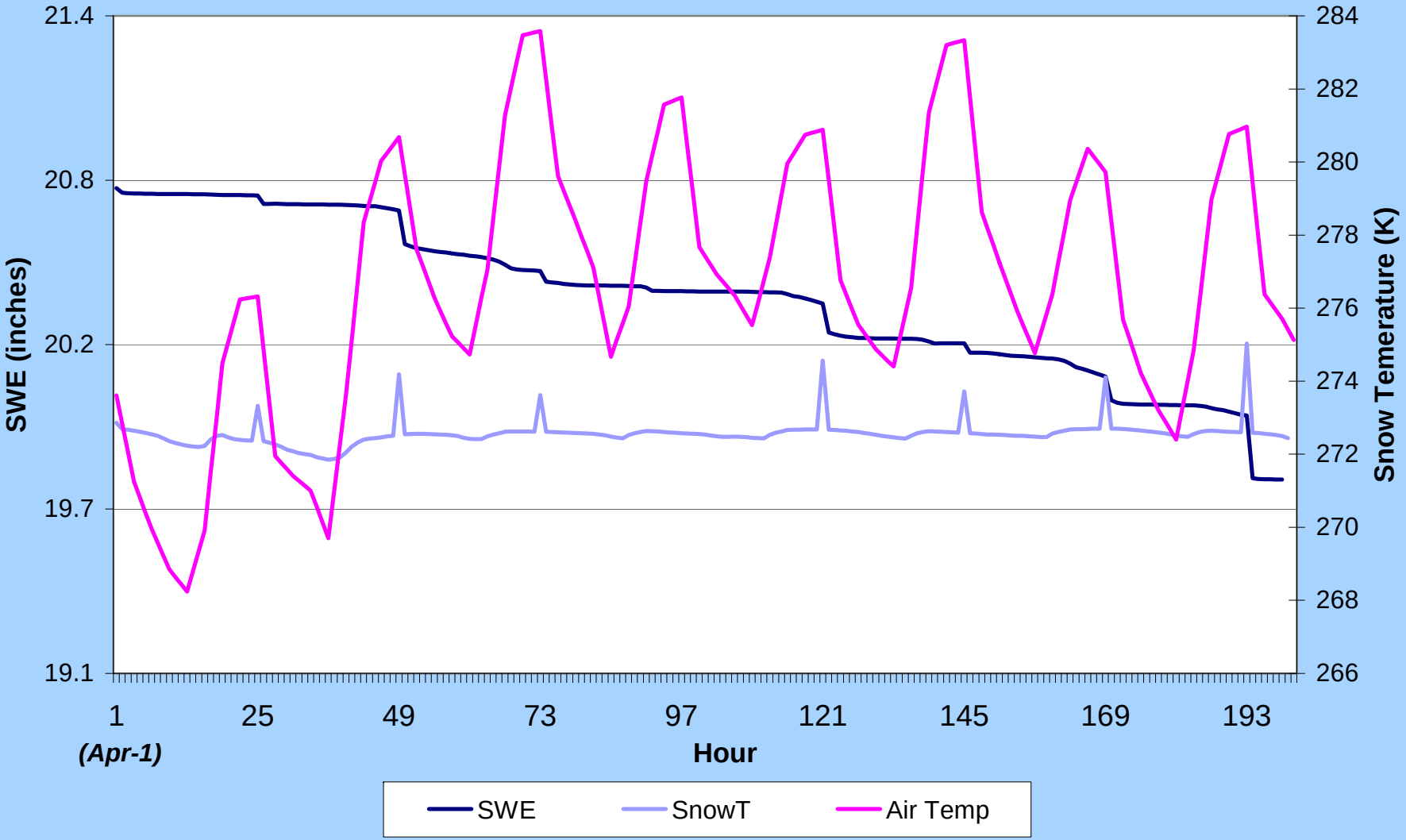
LSM Simulation (CLM2 Physics)

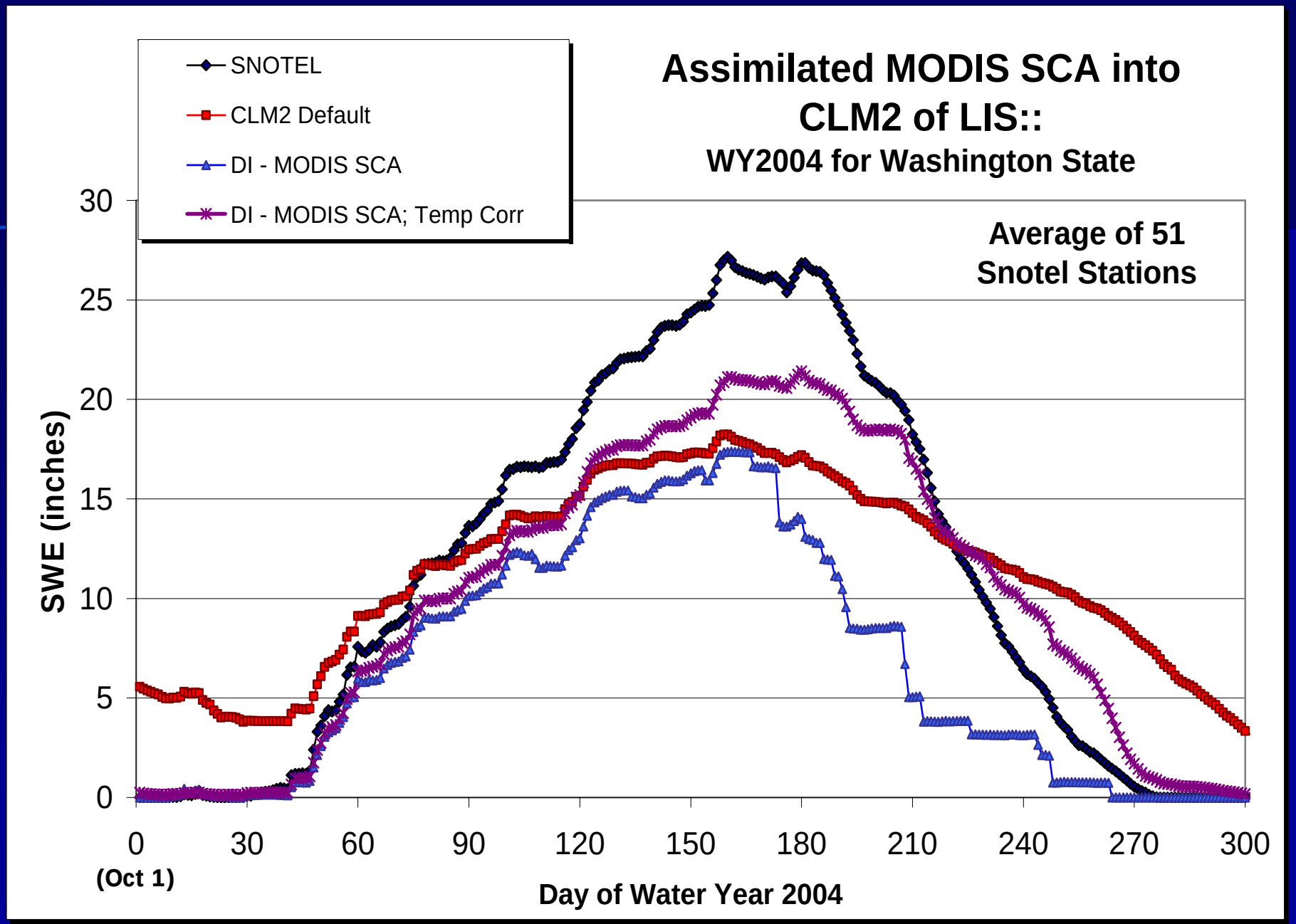
MODIS SCA Assimilation Step

- "Binary" SCA Obs ➔ Compare with LSM SWE
  - Initiate SWE in CLM2 when MODIS indicates SNOW
  - Modify CLM2 SWE when MODIS detects NO SNOW conditions
- Update CLM2 SWE by adjusting snow temperature with NLDAS air temperature (corrected with local LR)
- Update at 0Z (5:00 PM MST) to capture peak day temps;
  Hypothesis:: *Have most impact on snowmelt*

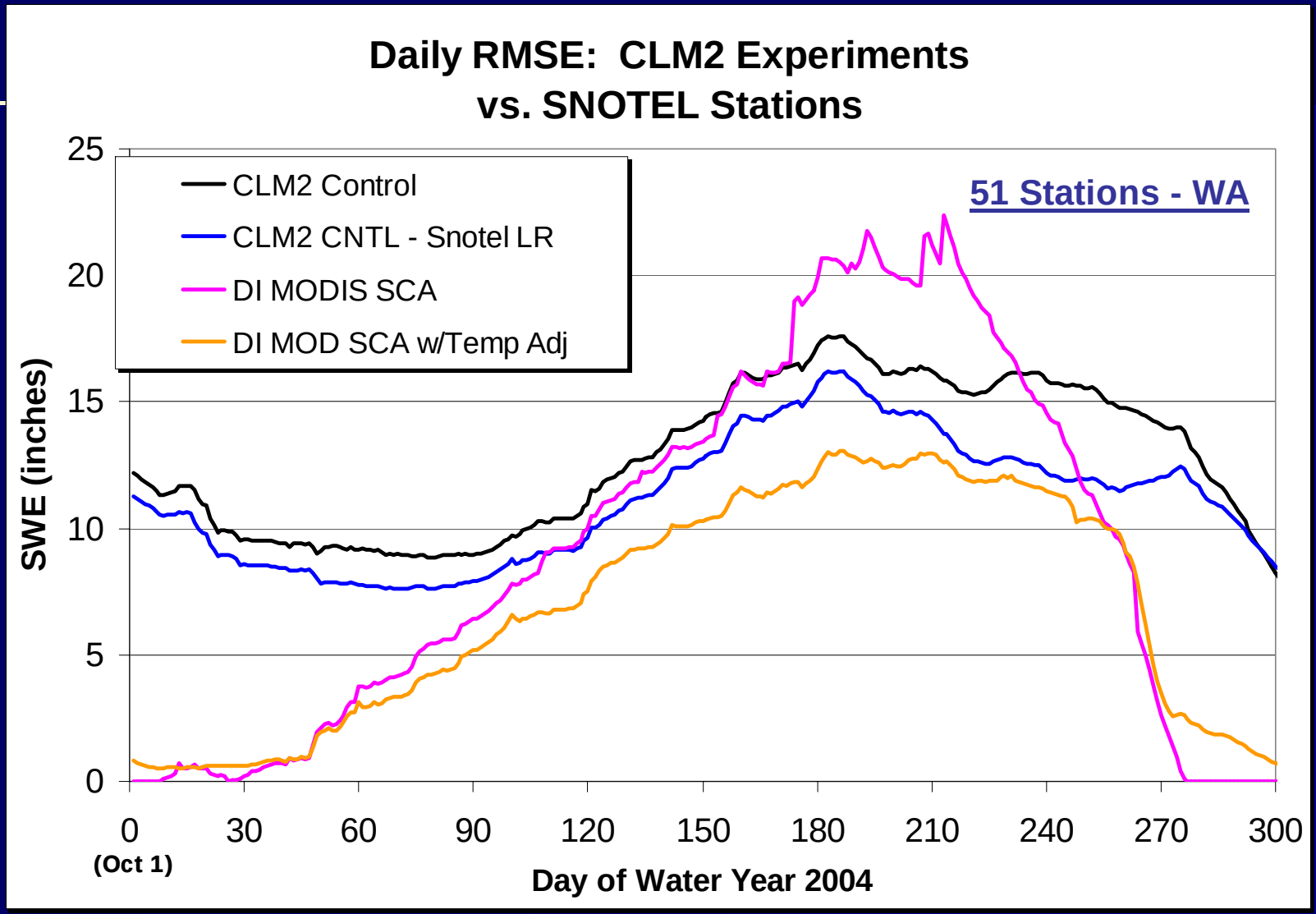
CLM2 - DI MODIS SCA; Temp. Adjustment

51 WA Stations -- SWE WY04




Assimilated MODIS SCA into CLM2 of LIS::
WY2004 for Washington State
SNOTEL
CLM2 Default
DI - MODIS SCA
DI - MODIS SCA; Temp Corr
Average of 51 Snotel Stations
SWE (inches)
0
5
10
15
20
25
30
0
30
60
90
120
150
180
210
240
270
300
(Oct 1)
Day of Water Year 2004

Daily RSME Values

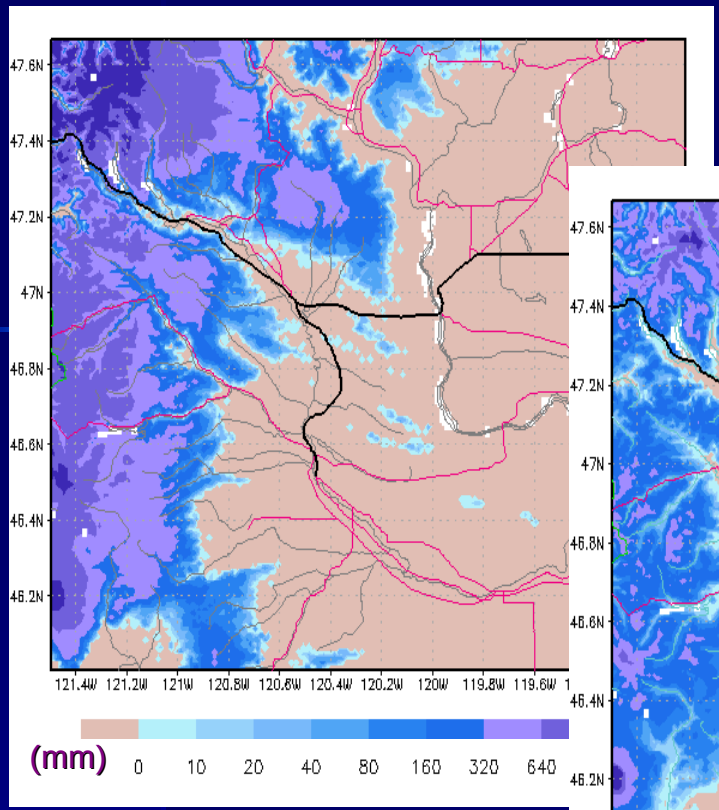


10) Yakima River Basin V&V

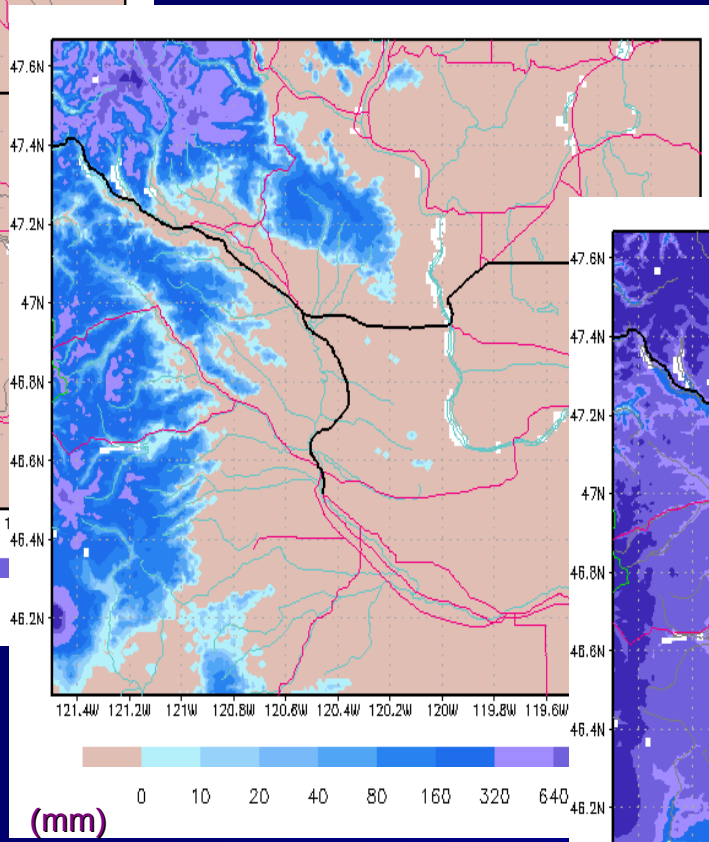
Yakima River Basin V&V

- Two time periods have been identified for this study to investigate the change in snow initialization of MMS daily forecasts, focusing on unregulated sub-basin areas in the Yakima River Basin.
- These two periods include:
  - (1) 2005 – major drought and very low-flow year (MMS did not capture well that year the needed inputs for RiverWare); and
  - (2) 2006 – which involved major snowmelt events.

Snow Water Equivalent (in mm)

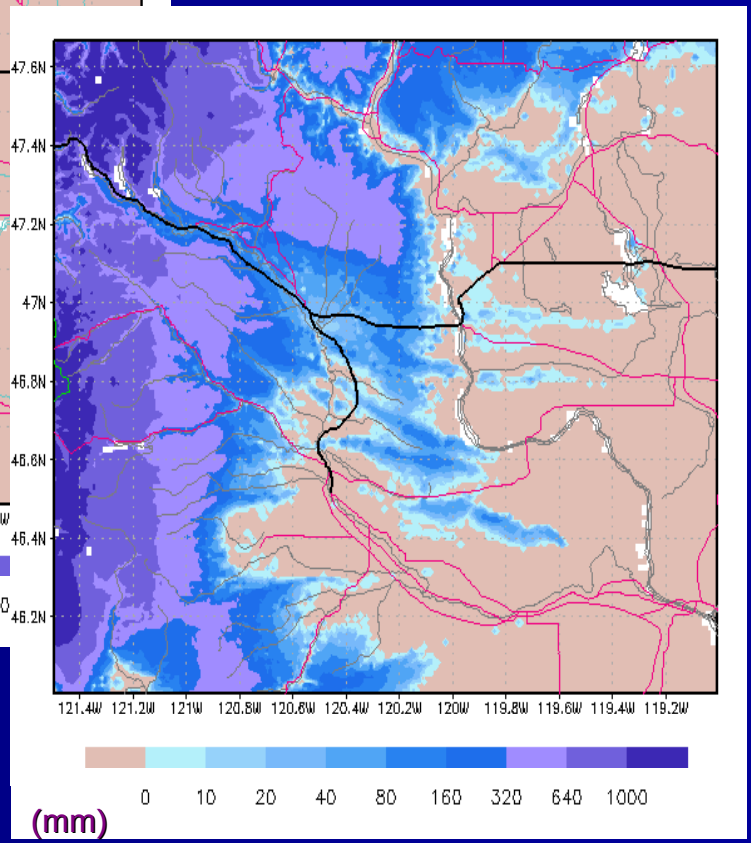


April 1, 2004 (08Z)
"Normal" Year



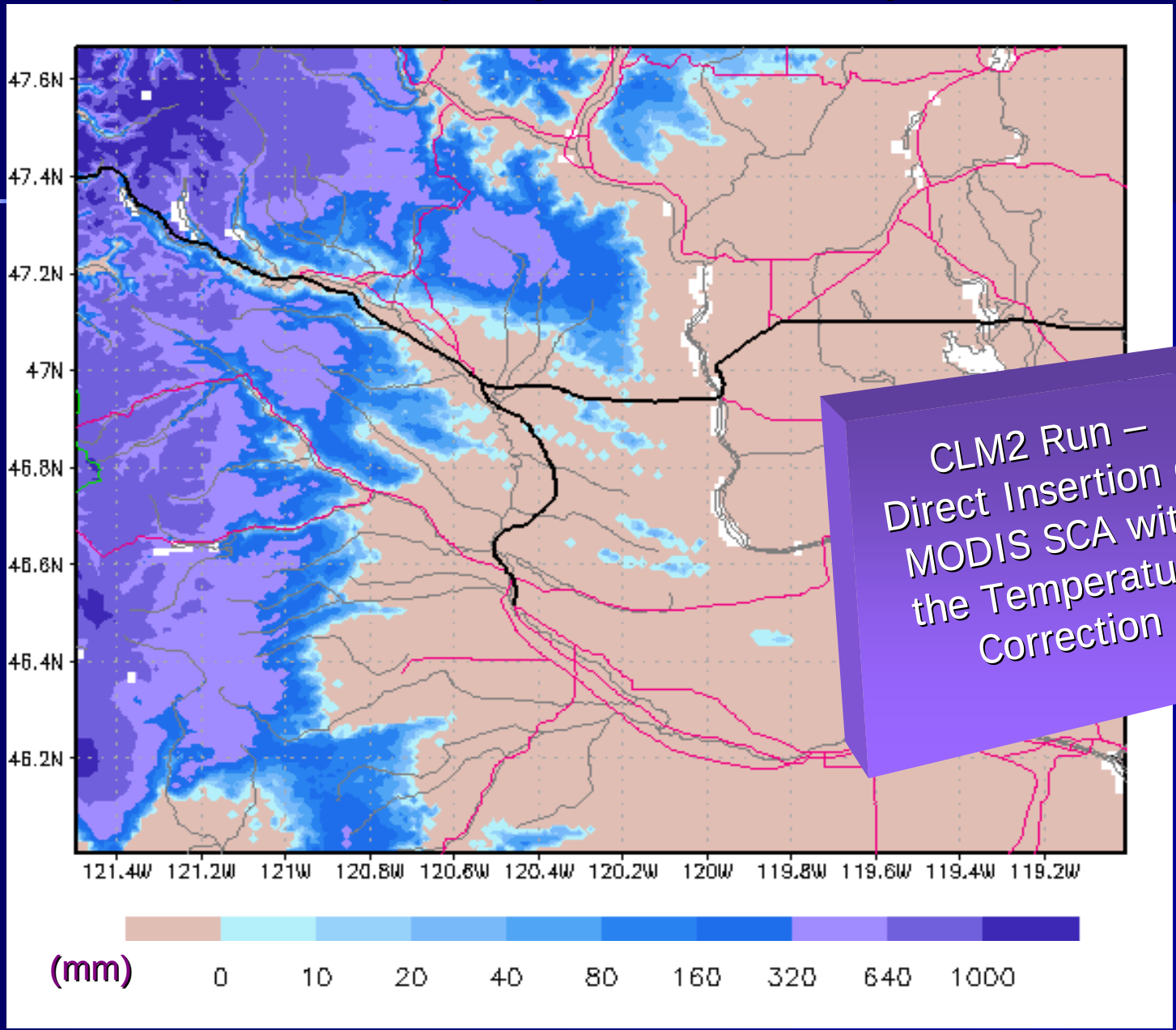
April 1, 2005 (08Z)
"Drought" Year

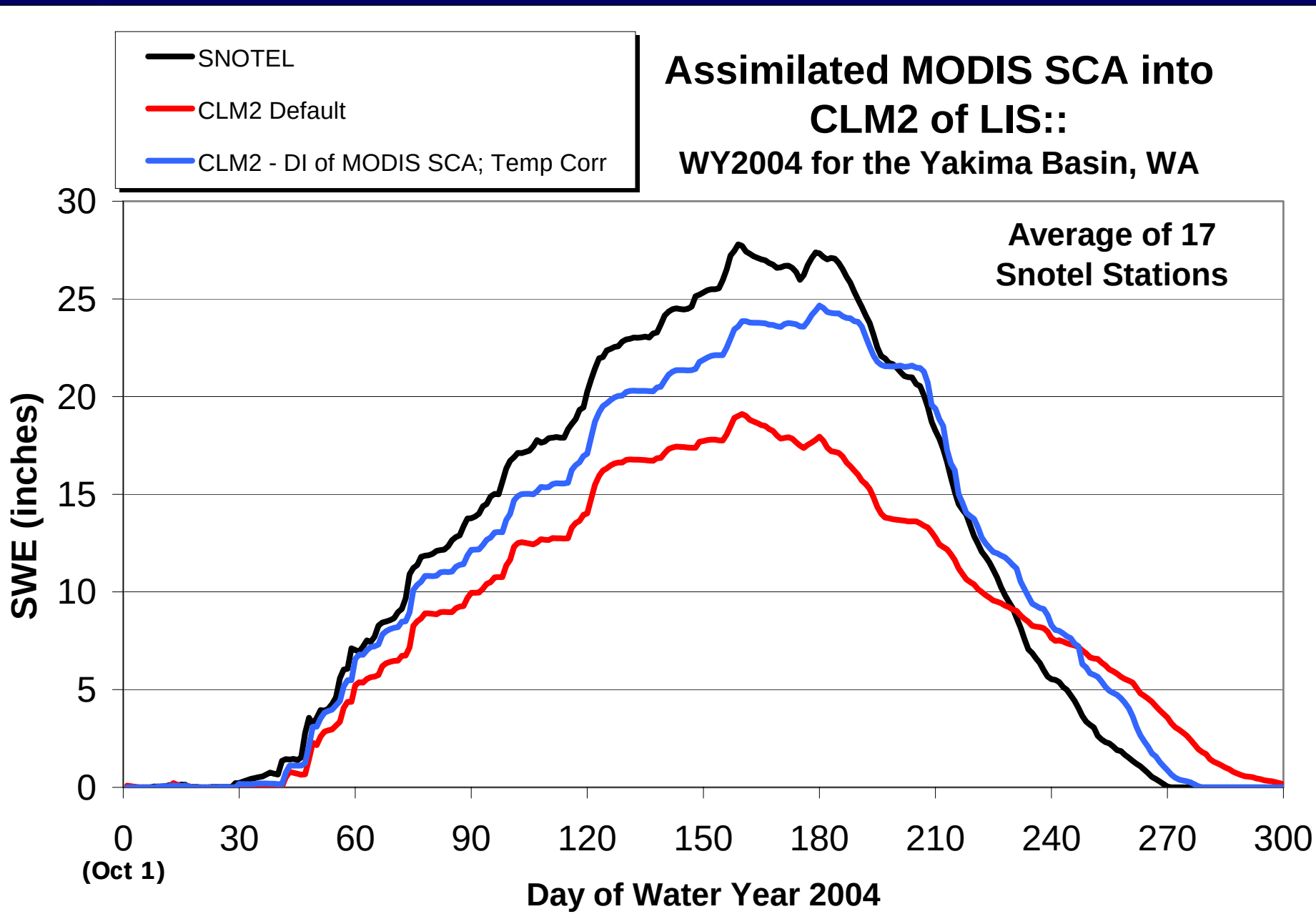
April 1, 2006 (08Z)
"Flood" Year



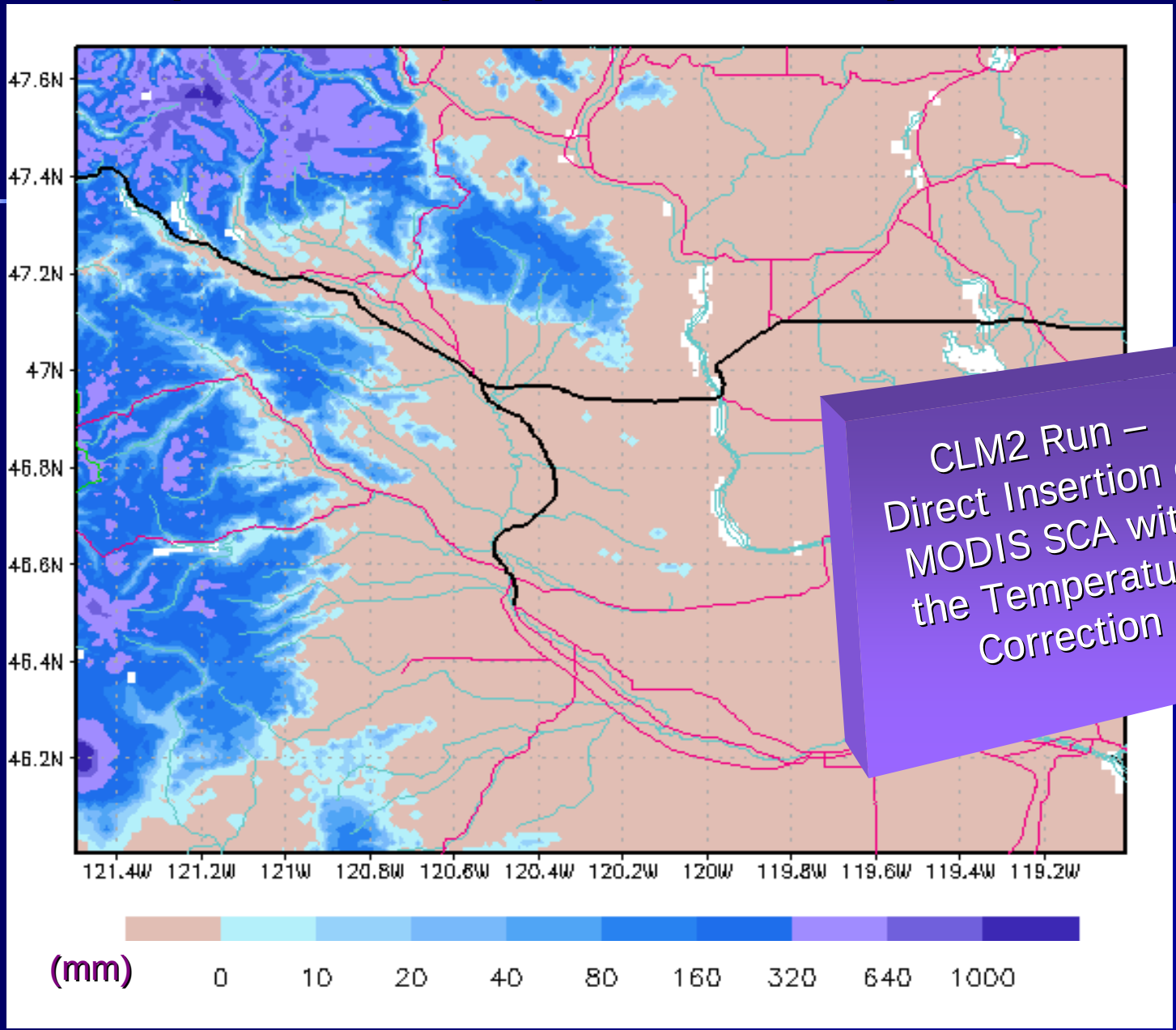
LIS CLM2 – Assimilated MODIS SCA Simulation with Temperature Correction:: 3-Year Comparison

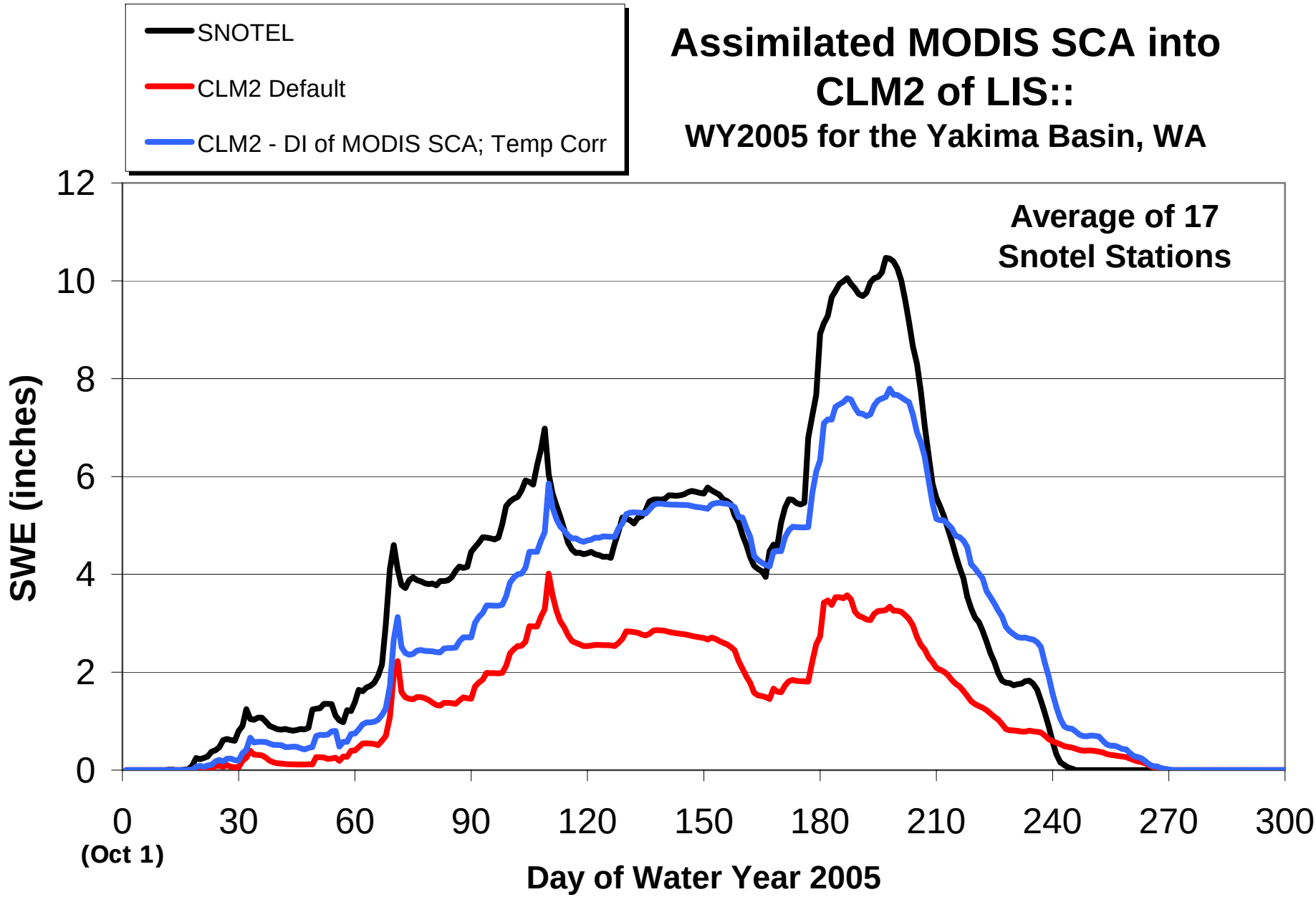
April 1, 2004 (08Z) Snow Water Equivalent



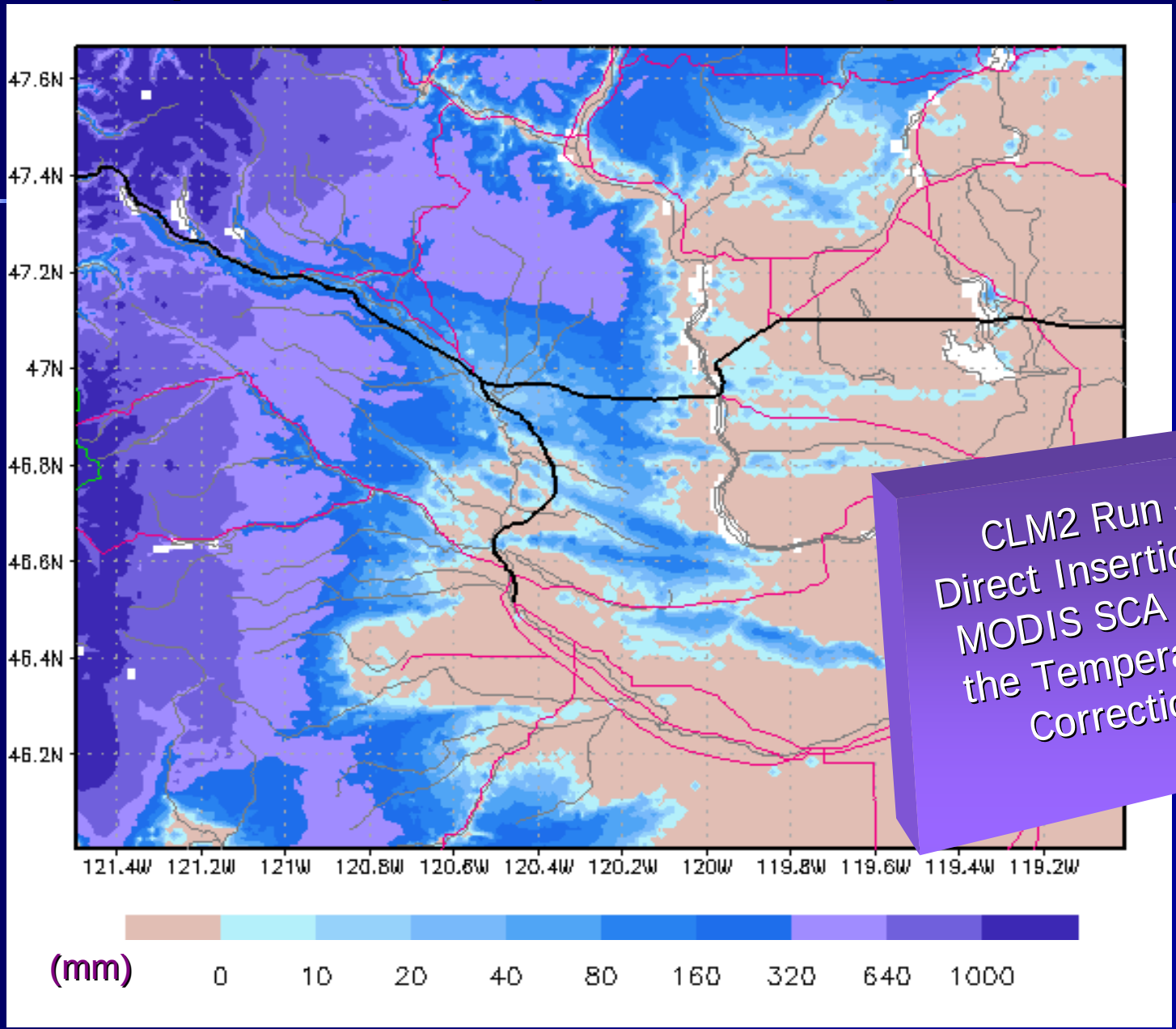

SNOTEL
CLM2 Default
CLM2 - DI of MODIS SCA; Temp Corr
Assimilated MODIS SCA into CLM2 of LIS::
WY2004 for the Yakima Basin, WA
Average of 17 Snotel Stations
SWE (inches)
0
5
10
15
20
25
30
0
(Oct 1)
30
60
90
120
150
180
210
240
270
300
Day of Water Year 2004

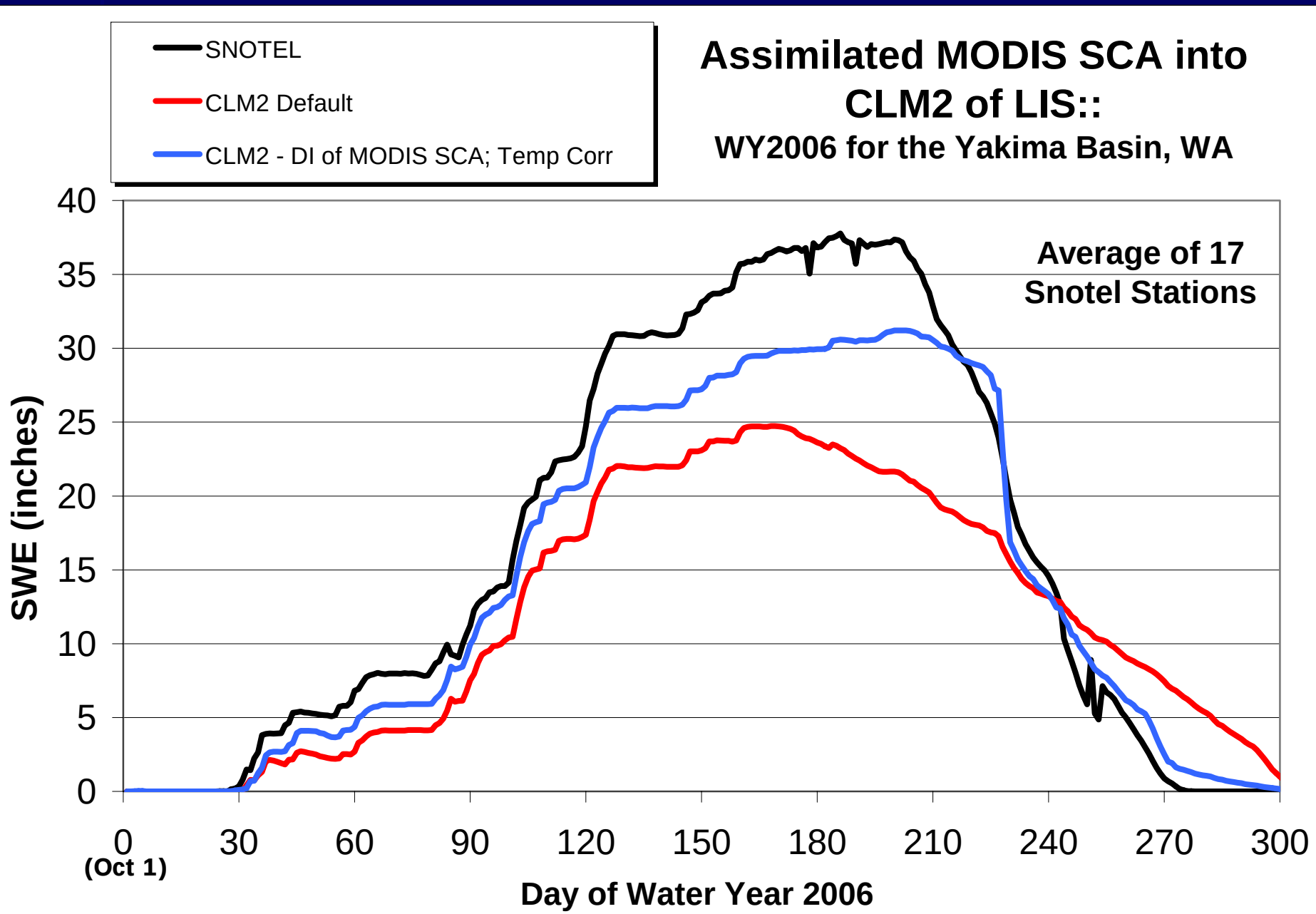
April 1, 2005 (08Z) Snow Water Equivalent




SNOTEL
CLM2 Default
CLM2 - DI of MODIS SCA; Temp Corr
Assimilated MODIS SCA into CLM2 of LIS::
WY2005 for the Yakima Basin, WA
Average of 17 Snotel Stations
SWE (inches)
0
2
4
6
8
10
12
0
(Oct 1)
30
60
90
120
150
180
210
240
270
300
Day of Water Year 2005

April 1, 2006 (08Z) Snow Water Equivalent




SNOTEL
CLM2 Default
CLM2 - DI of MODIS SCA; Temp Corr
Assimilated MODIS SCA into CLM2 of LIS::
WY2006 for the Yakima Basin, WA
Average of 17 Snotel Stations
SWE (inches)
0
5
10
15
20
25
30
35
40
0 (Oct 1)
30
60
90
120
150
180
210
240
270
300
Day of Water Year 2006

11) Summary and Conclusions

Summary

- The NASA LIS modeling framework was used to generate modeled snowpack fields to be provided to the USBR Yakima Office to initialize their operational hydrological model, MMS, and DST, RiverWare
- Validated MODIS SCA and evaluated its applicability for assimilation into CLM2
- Examined some of the biases in LIS CLM2 snow physics, parameters and forcings
- Utilized these biases to help establish direct insertion approach for CLM2

Summary (con't)

- MODIS SCA was used to "guide" CLM2 in the assimilation process by making an adjustment to each snow temperature layer using the NLDAS air temperature
- This adjustment acts to "warm" the snow layers, in place of the snow fraction biases and underestimated penetration of shortwave radiation, melting the snow more when observed air temperatures tend to remain above the freezing point
- Final outcome::

  CLM2 SWE was improved for three years of simulation

Gaps or Limitations of V&V Process

- The current validation objectives were addressed with retrospective cases. However, USBR is most interested in doing operational and forecast simulations.
- The V&V process should also have included at least a real-time mode.
- One problem though for real-time or forecast simulations is the delay in time from receiving and processing MODIS bands into products and making those products available in near real-time. If clouds obscure a daily product, then an older MODIS image could be used or simply using the model “as is”, accounting for any biases the model may have.

Gaps or Limitations of V&V Process (con't)

- The 500m MODIS SCA v4 product is "binary" (snow/no-snow), which can be difficult to validate with in-situ measurements like SNOTEL. For example, SNOTEL sites may represent only a small fraction of snow in a "non-snow" classified MODIS pixel, though the majority of the area was truly snow-free.
- Validation of the MODIS LAI product is also difficult due to the lack of ground-truth observations to validate the product in this area.
- The LIS modeled runoff should have been routed and compared with stream gage measurements for validation of volume and flow in unregulated basins, independent of testing with MMS and RiverWare

Recommendations

- Validate Collection 5 MODIS Products and the latest version of CLM 3.5 in LIS
- Test NASA near real-time products to see how well they can perform in the DST in a more operational setting
- Provide validated results to MODIS satellite algorithm development teams; potentially use information for further development of future product versions
- Set up and validate satellite datasets and LIS LSMs for over USBR regions

Connecting the V&V to the Benchmark Process and Reporting

- Following this V&V Report, benchmark metrics are used to compare MMS and RiverWare output before and after the inclusion of the NASA satellite and modeled integrated output.
- Benchmark metrics and procedures are defined with “target” hydrographs which are based on independent streamflow and height observations
- Two case years will be used for the benchmarking process: a low flow year and a flood-based year
- It is hoped that improvements to Reclamation DSTs using NASA products will lead to operational use by Reclamation and other partnering agencies.